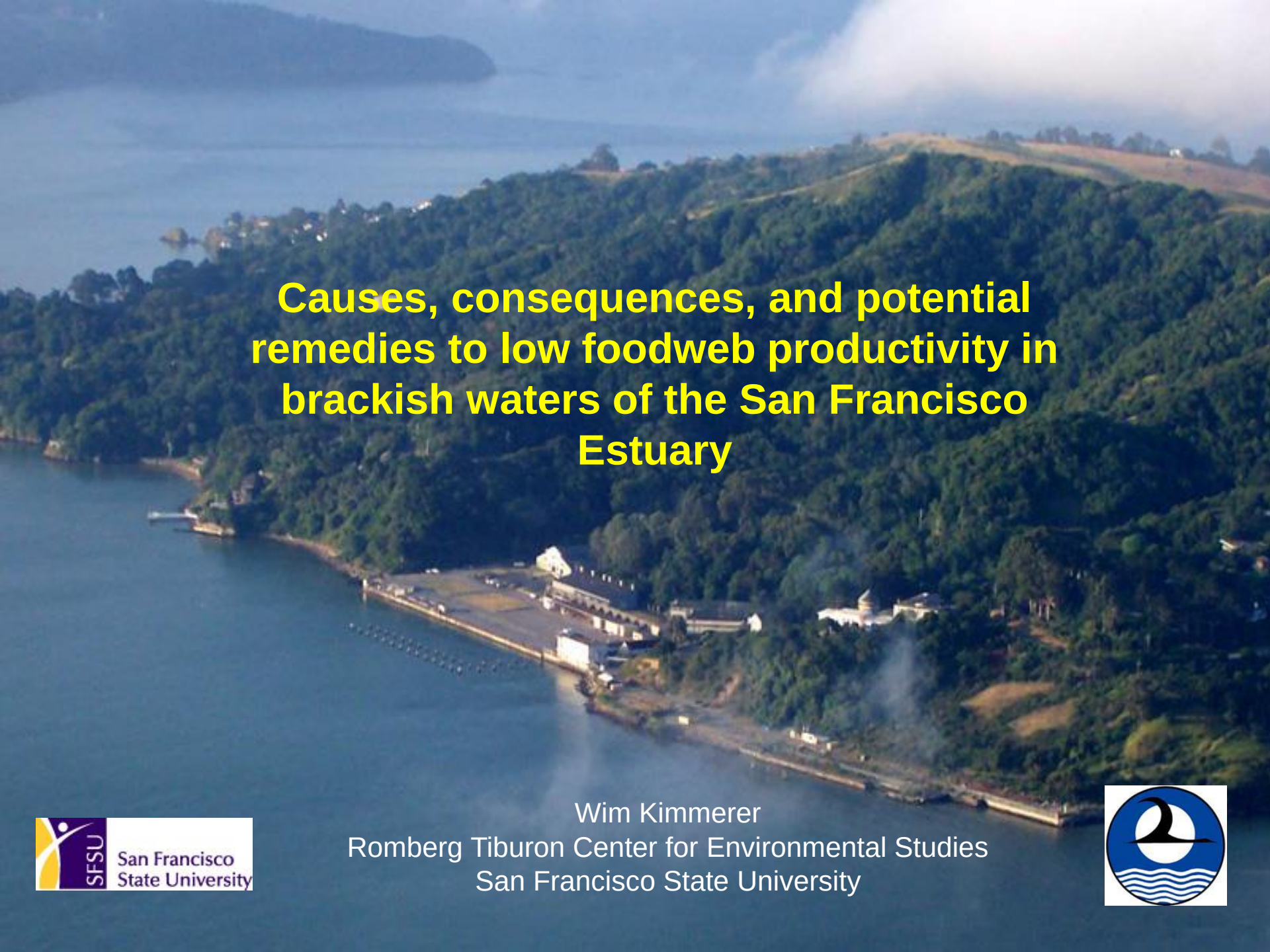


Causes, consequences, and potential remedies to low foodweb productivity in brackish waters of the San Francisco Estuary

Wim Kimmerer
Romberg Tiburon Center for Environmental Studies
San Francisco State University

How much food and why?

I'm hungry!

??

Which foodweb?

- Freshwater Delta
- Low-Salinity Zone (LSZ, ~ 0.5 – 5 or 10)
- Salty regions – South Bay-San Pablo Bay

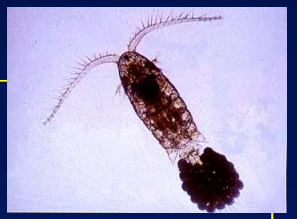
Main points

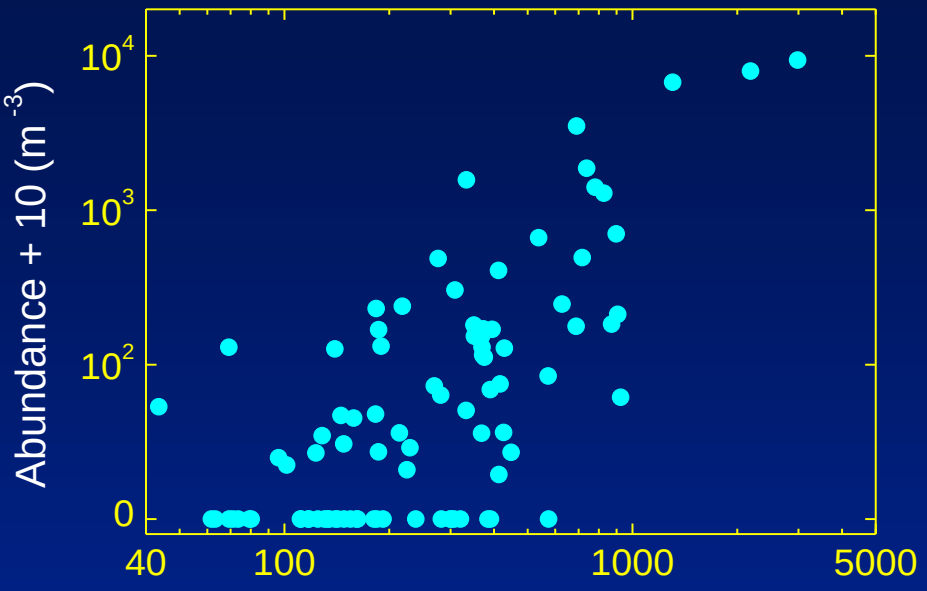
1. Plankton are quasi-Lagrangian particles
2. Limits to primary production
3. Consequent limits to zooplankton production
4. Spatial subsidies
5. How to design an estuarine copepod
6. Can we fix the low productivity?
7. Some key questions

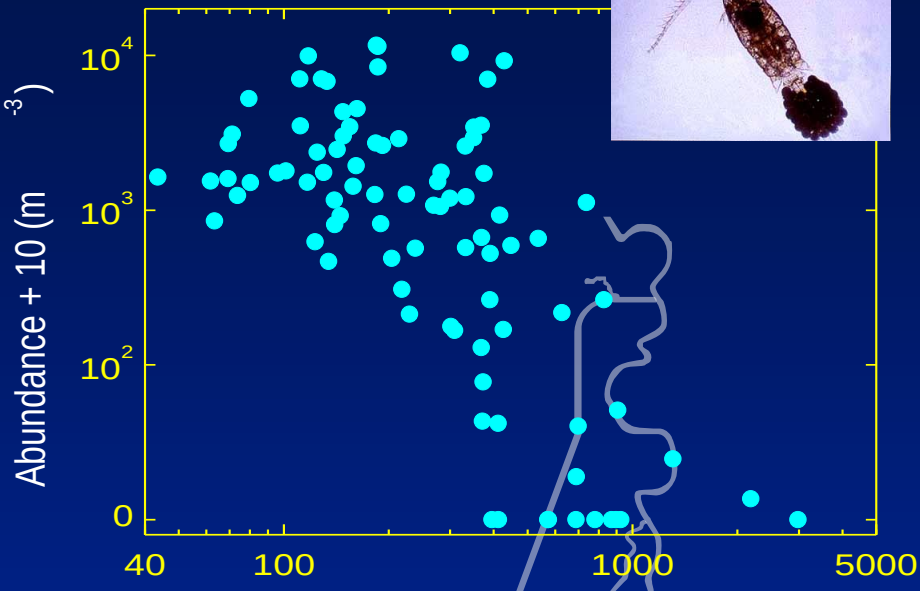
Some old stuff, some new!

1. Plankton are quasi-Lagrangian particles

Eurytemora affinis Abundance vs. Freshwater Flow







San Francisco Estuary:

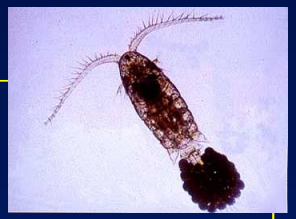
River km 61

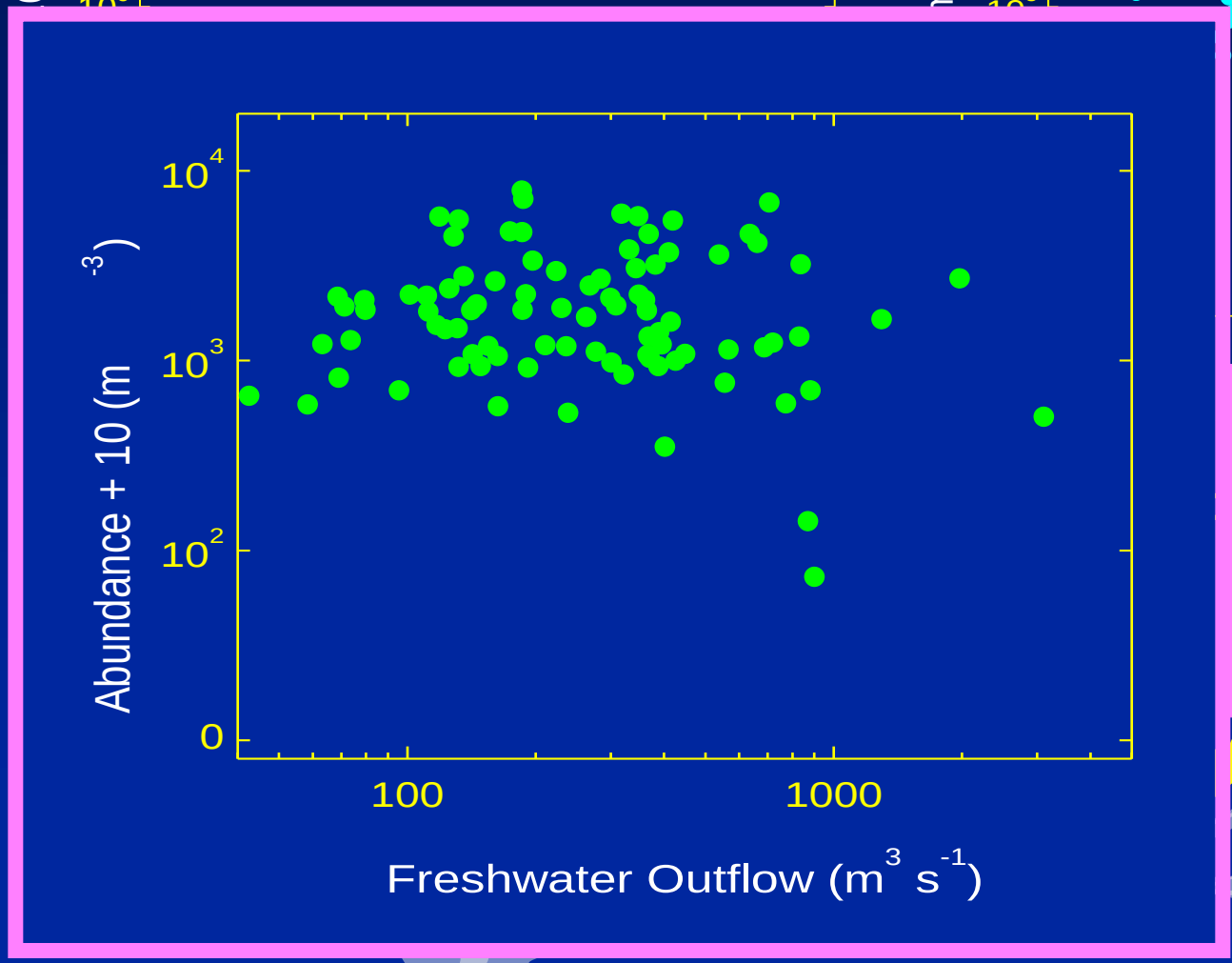
River km 83

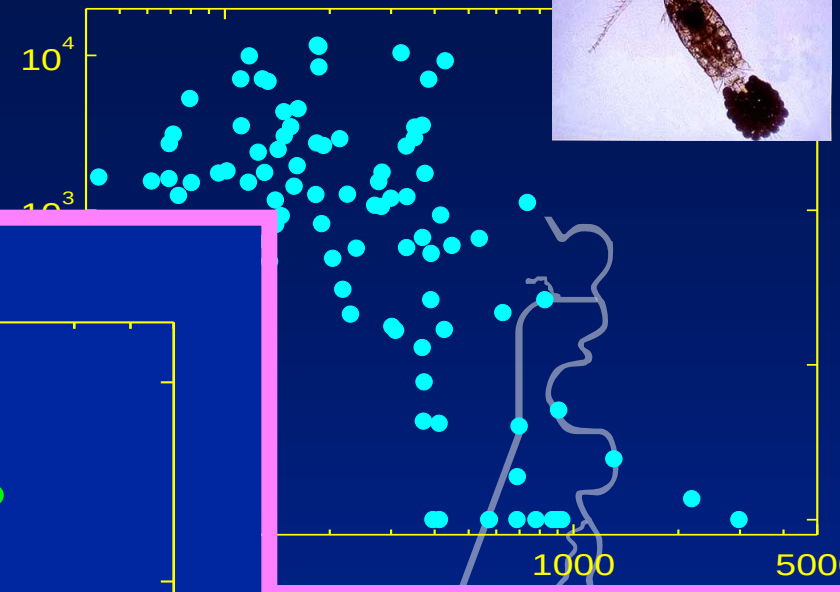
IEP Monitoring 1972-86

1. Plankton are quasi-Lagrangian particles

Eurytemora affinis Abundance vs. Freshwater Flow





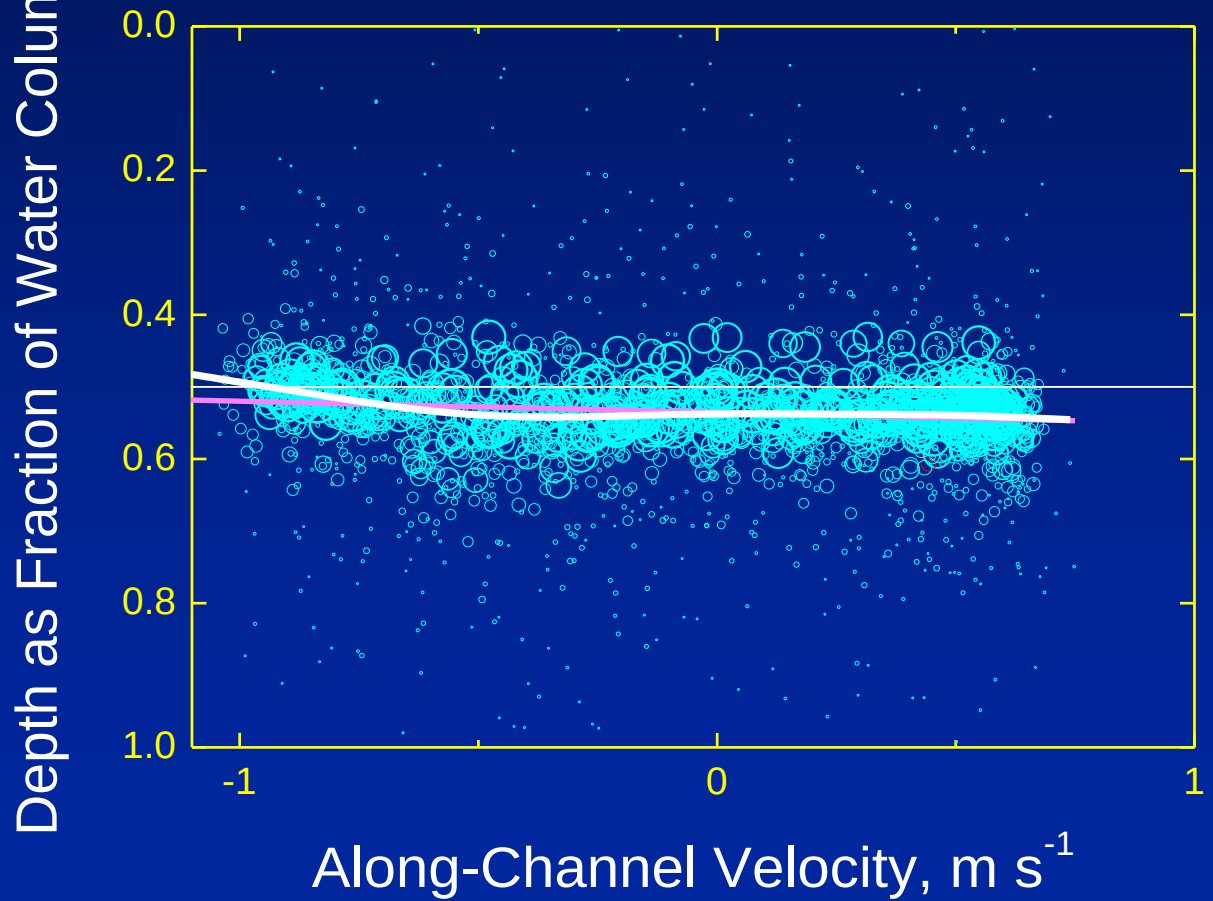


Lagrangian frame of reference:
Means for salinity 0.5 – 6 show little effect of flow

1. Plankton are quasi-Lagrangian particles: why quasi

Effect of particle behavior on vertical position

Neutrally Buoyant



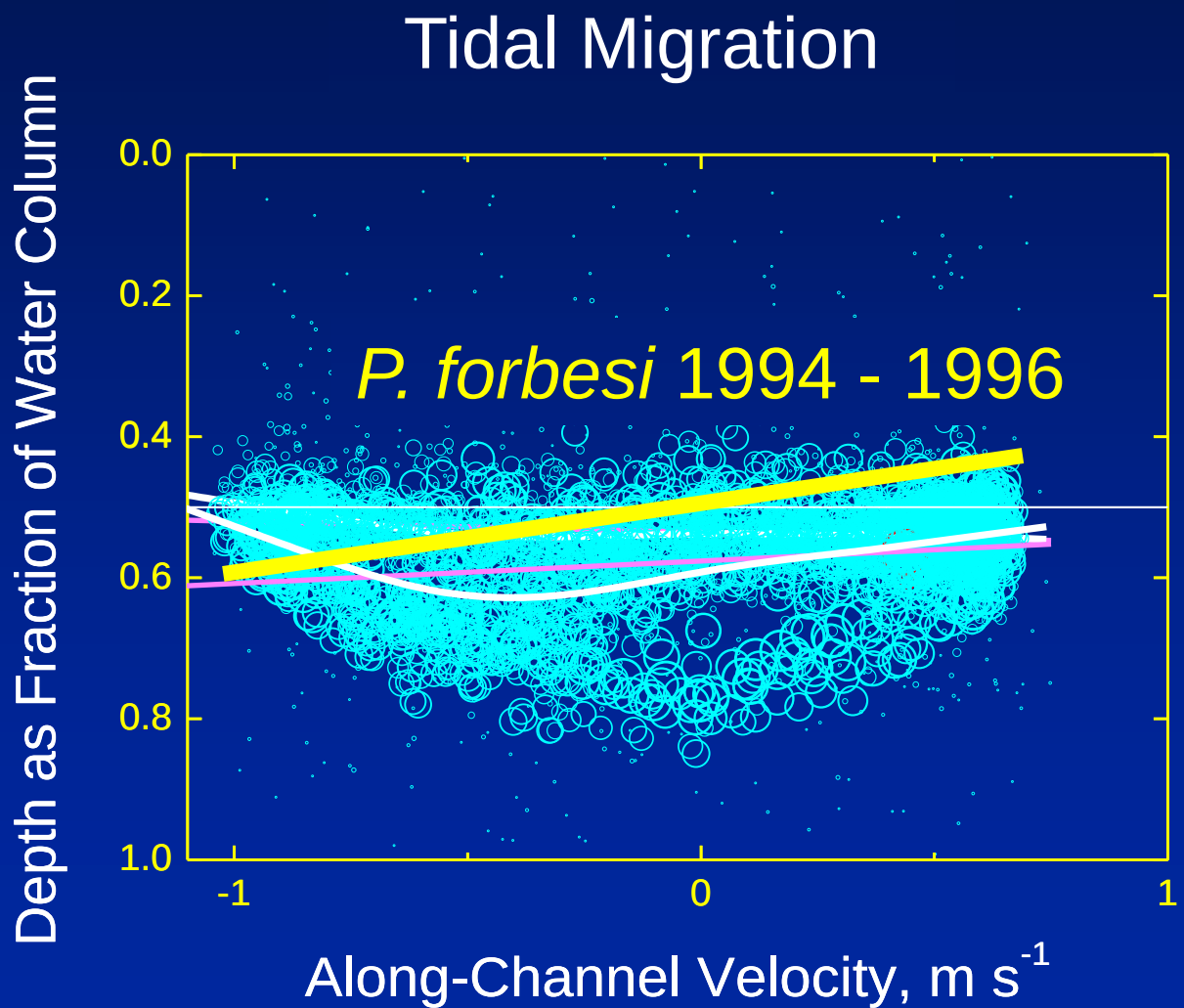
Areas of circles ∝ number of particles

1128 particles (max)

Kimmerer Gross MacWIlliams
In Press Limnol. Oceanogr.

1. Plankton are quasi-Lagrangian particles: why quasi

Effect of particle behavior on vertical position



Areas of circles ∝ number of particles

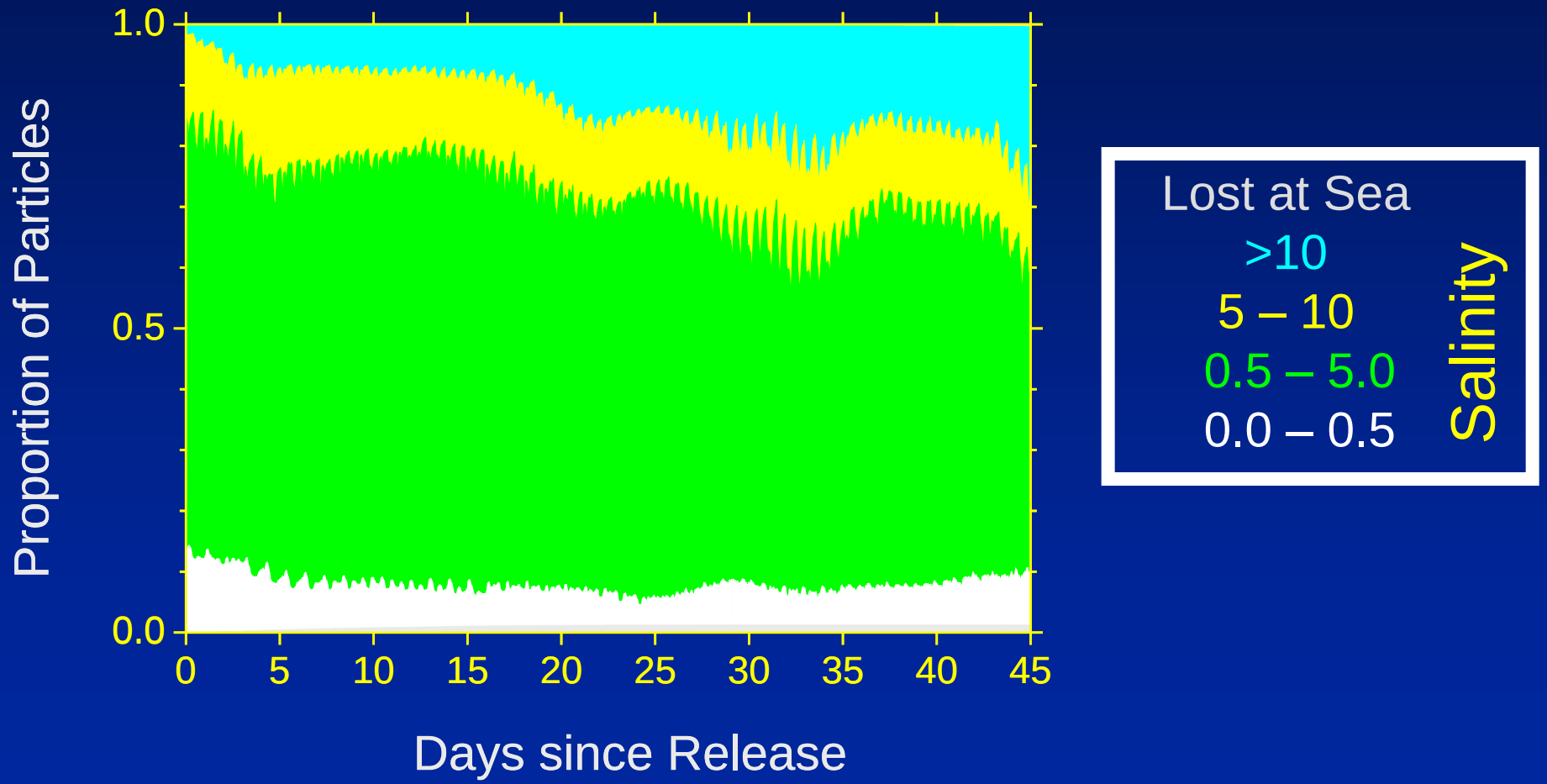
1128 particles (max)

Kimmerer Gross MacWIlliams
In Press Limnol. Oceanogr.

1. Plankton are quasi-Lagrangian particles : why quasi

Effect of particle behavior on transport

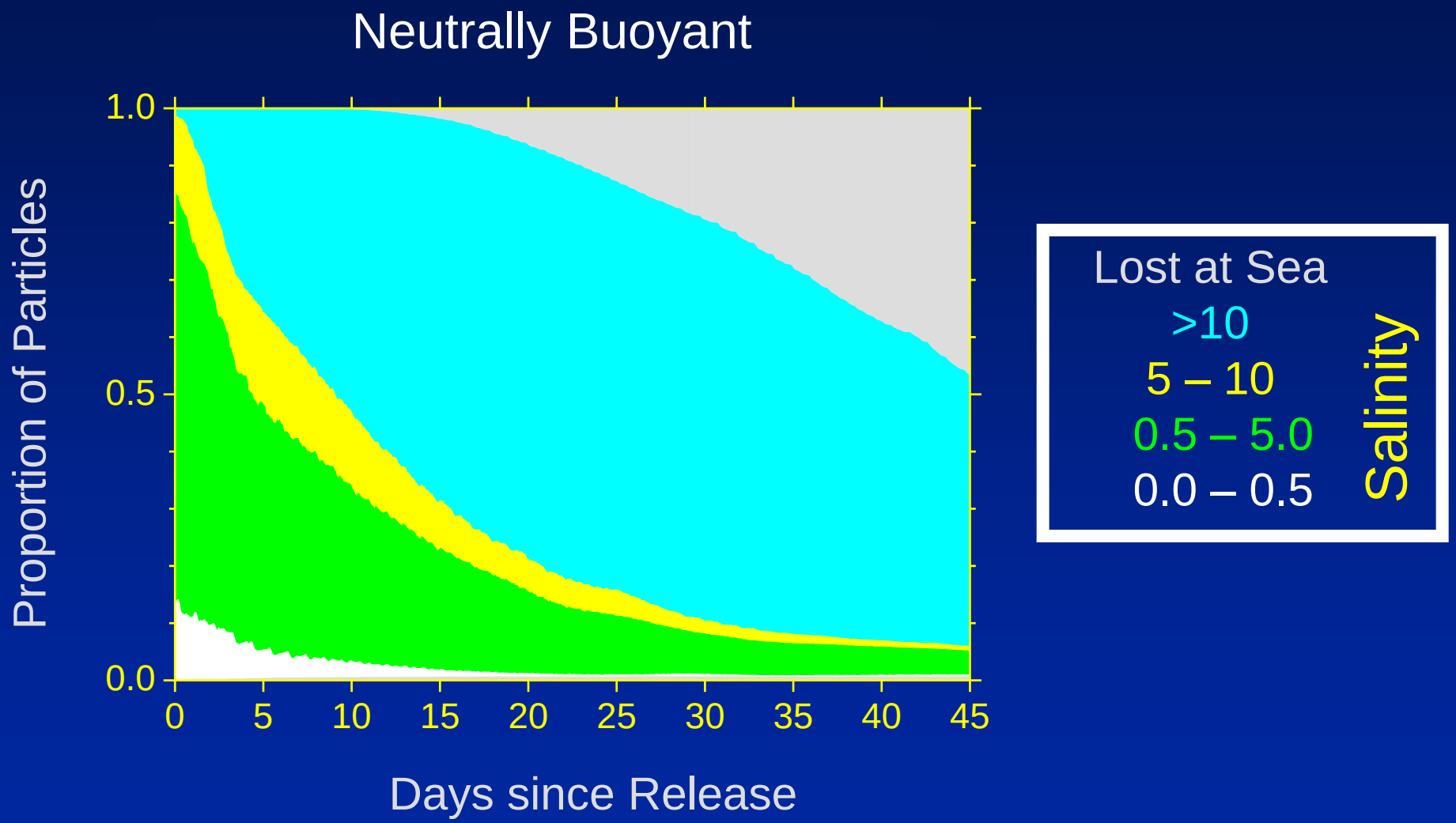
Tidal Biased ⇓ on ebb ⇑ on flood



Kimmerer Gross MacWIlliams
In Press Limnol. Oceanogr.

1. Plankton are quasi-Lagrangian particles : why quasi

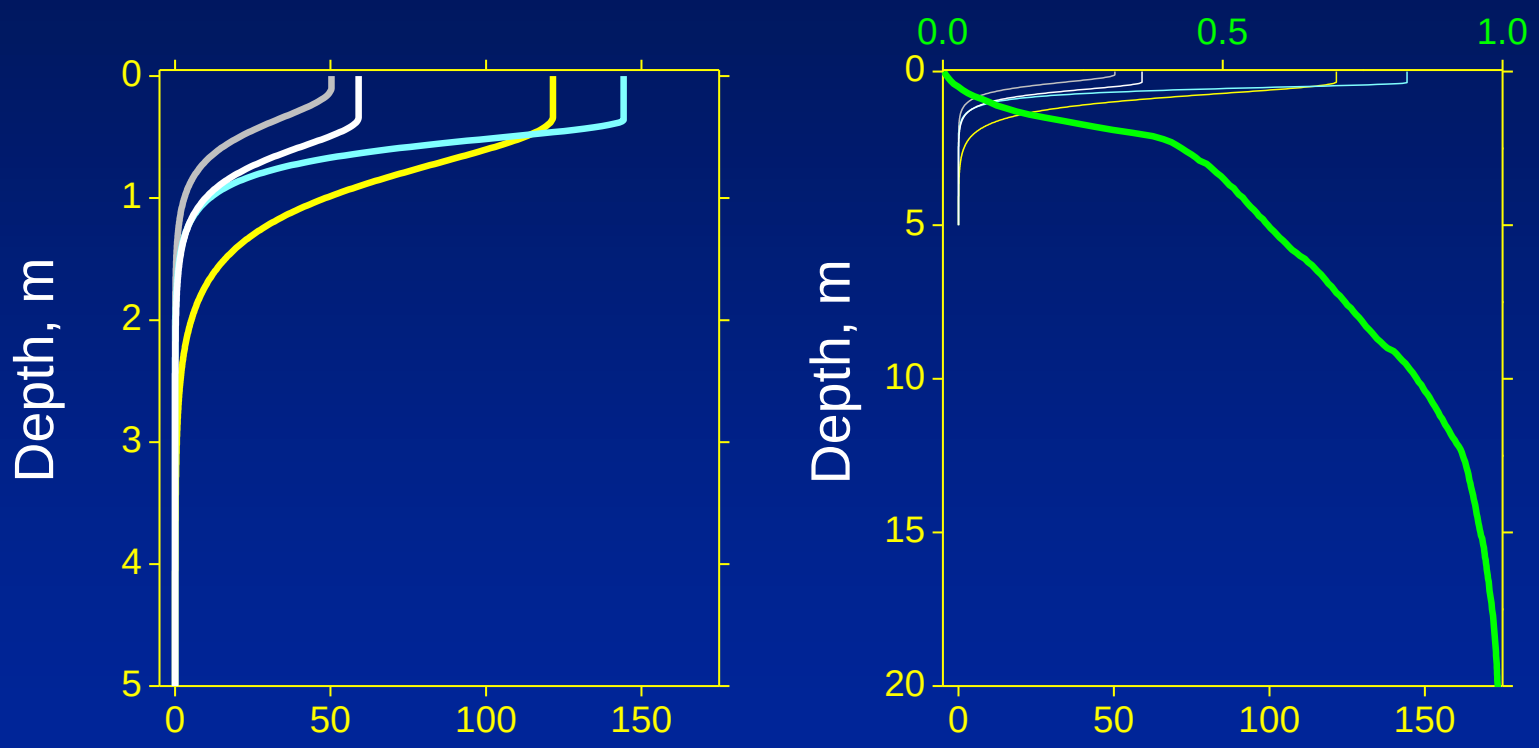
Effect of particle behavior on transport



Kimmerer Gross MacWIlliams
In Press Limnol. Oceanogr.

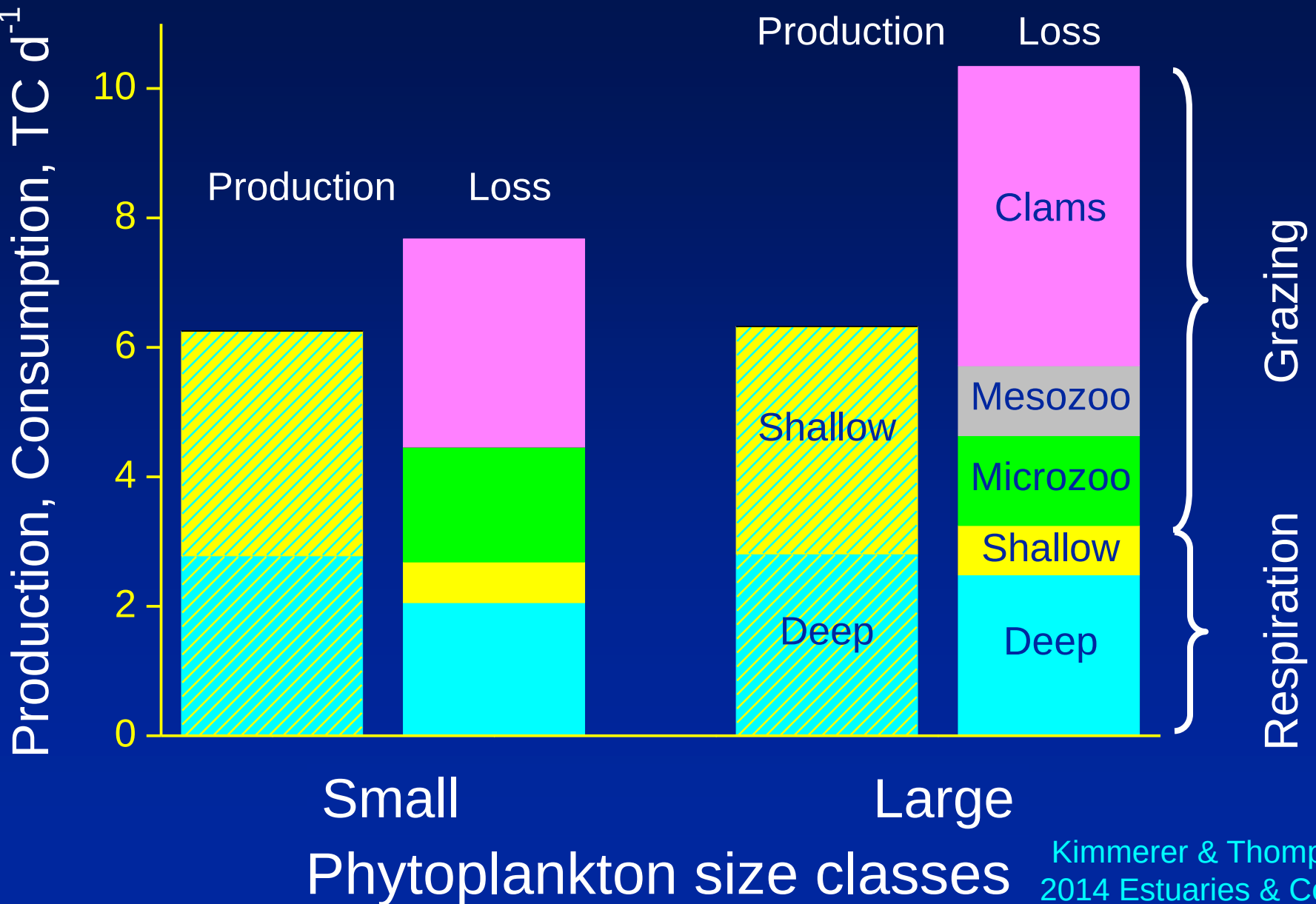
2. Limits to primary production: light

Primary production
Examples
LSZ 2006 - 2007



Kimmerer et al. 2012
Estuaries & Coasts

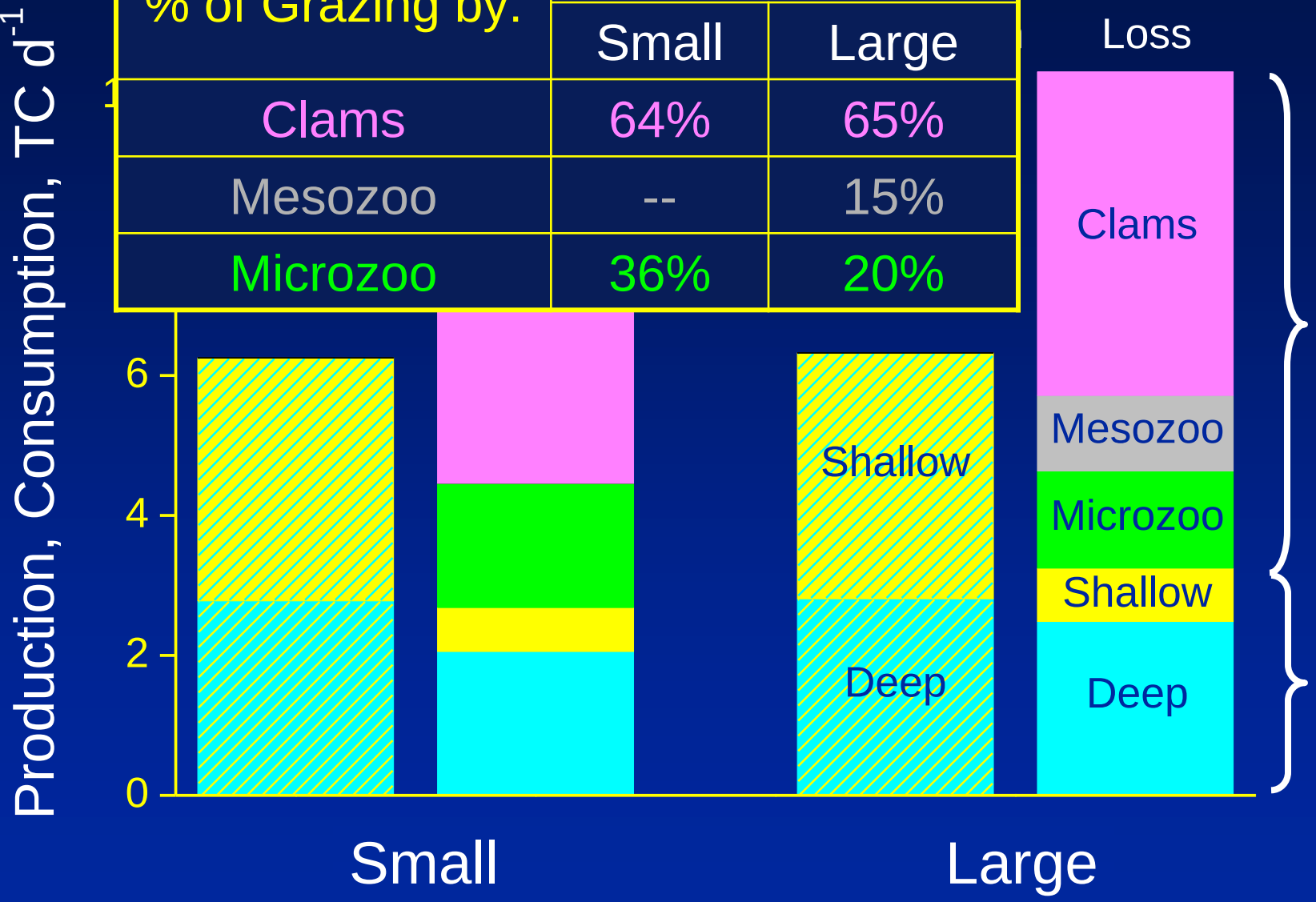
2. Limits to primary production: Grazing



Kimmerer & Thompson
2014 Estuaries & Coasts

2. Limits to primary production: Grazing

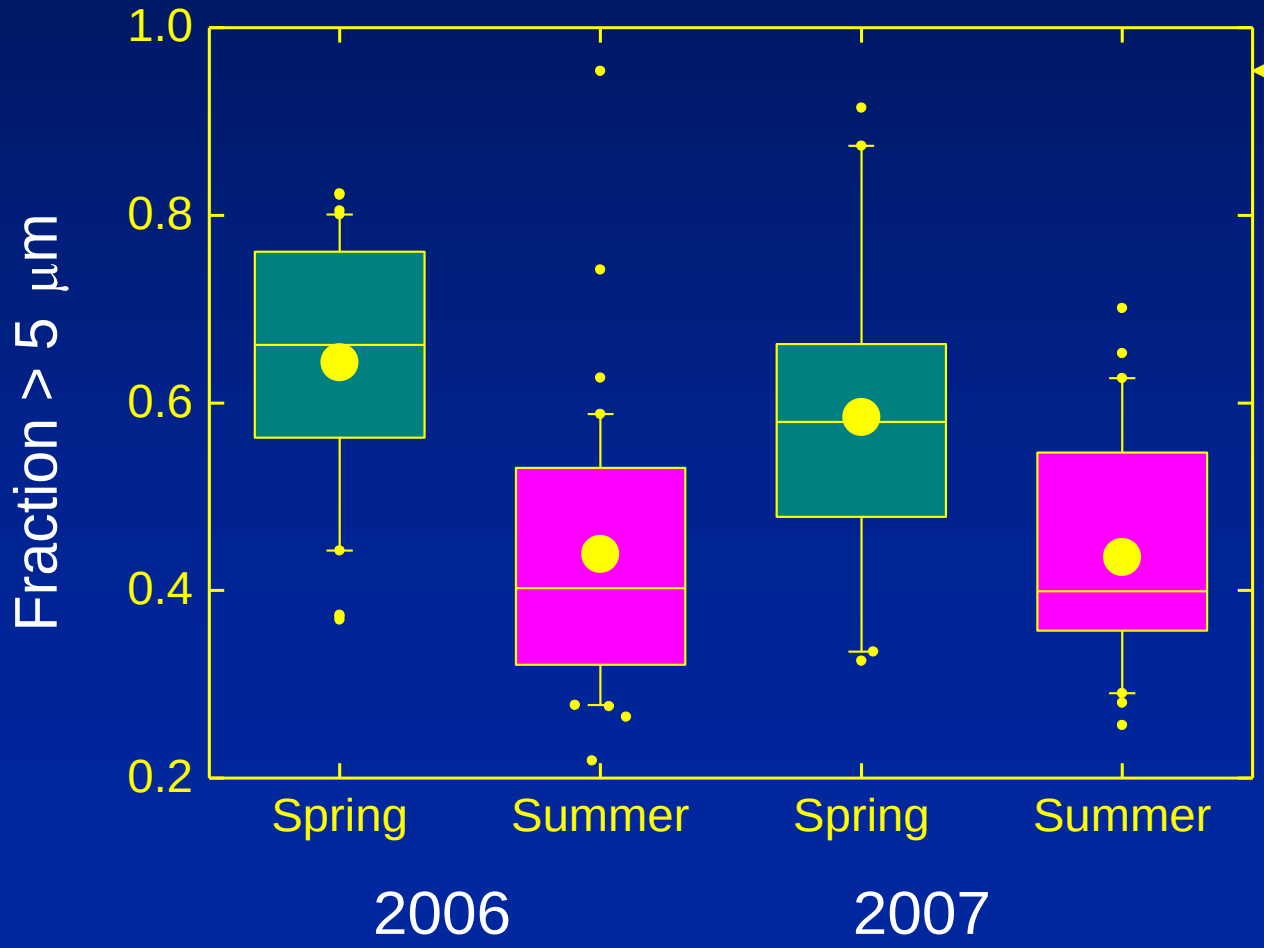
% of Grazing by:	Phytoplankton	
	Small	Large
Clams	64%	65%
Mesozoo	--	15%
Microzoo	36%	20%



Kimmerer & Thompson
2014 Estuaries & Coasts

2. Limits to primary production: Size fractions

111 paired sets of ^{14}C incubations
5 µm and GF/F filter

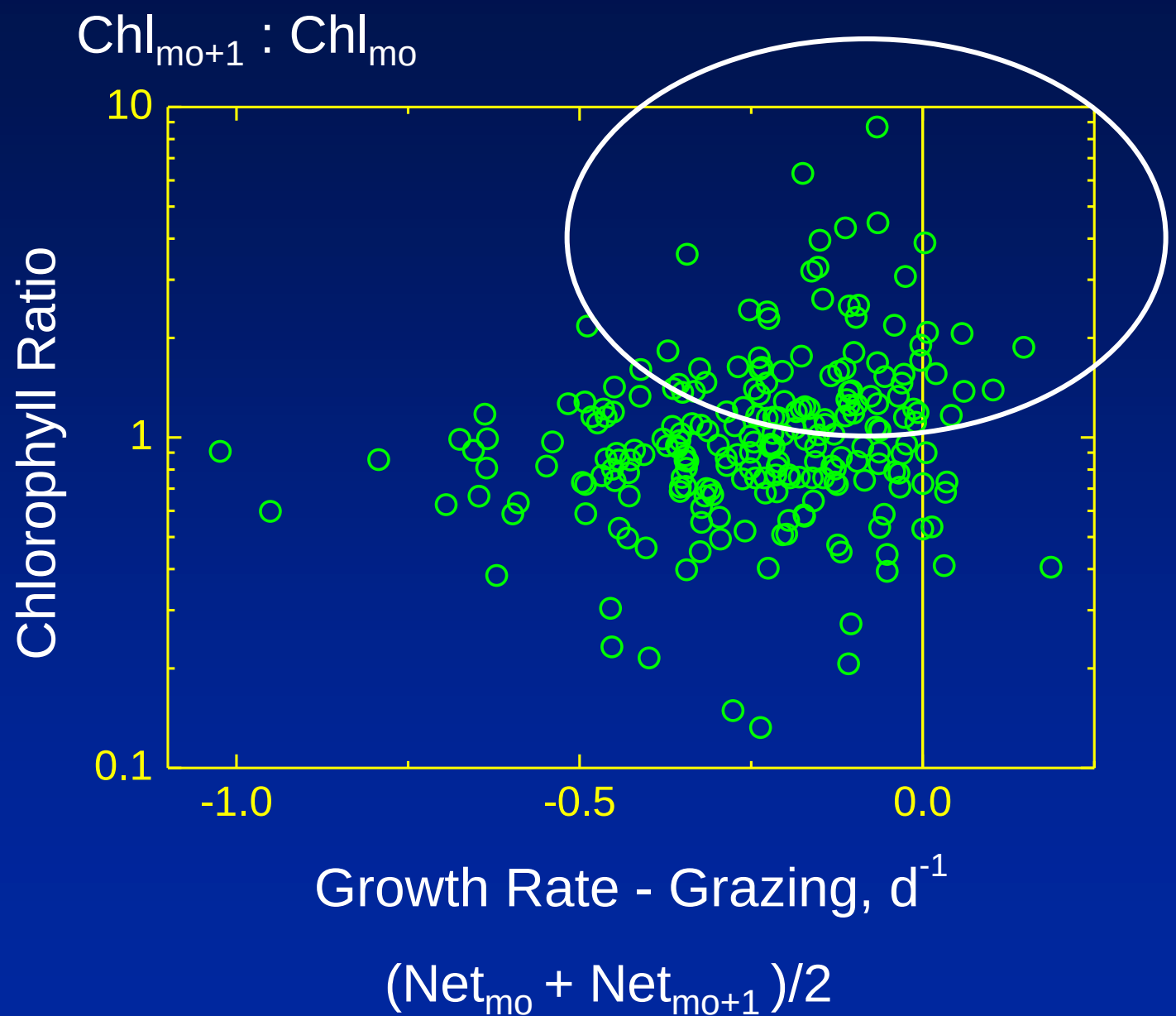


1980 Mean

Particles < ~ 5 µm less available to both copepods and clams

Kimmerer et al. 2012
Estuaries & Coasts

2. Limits to primary production: Net growth 1987-2008

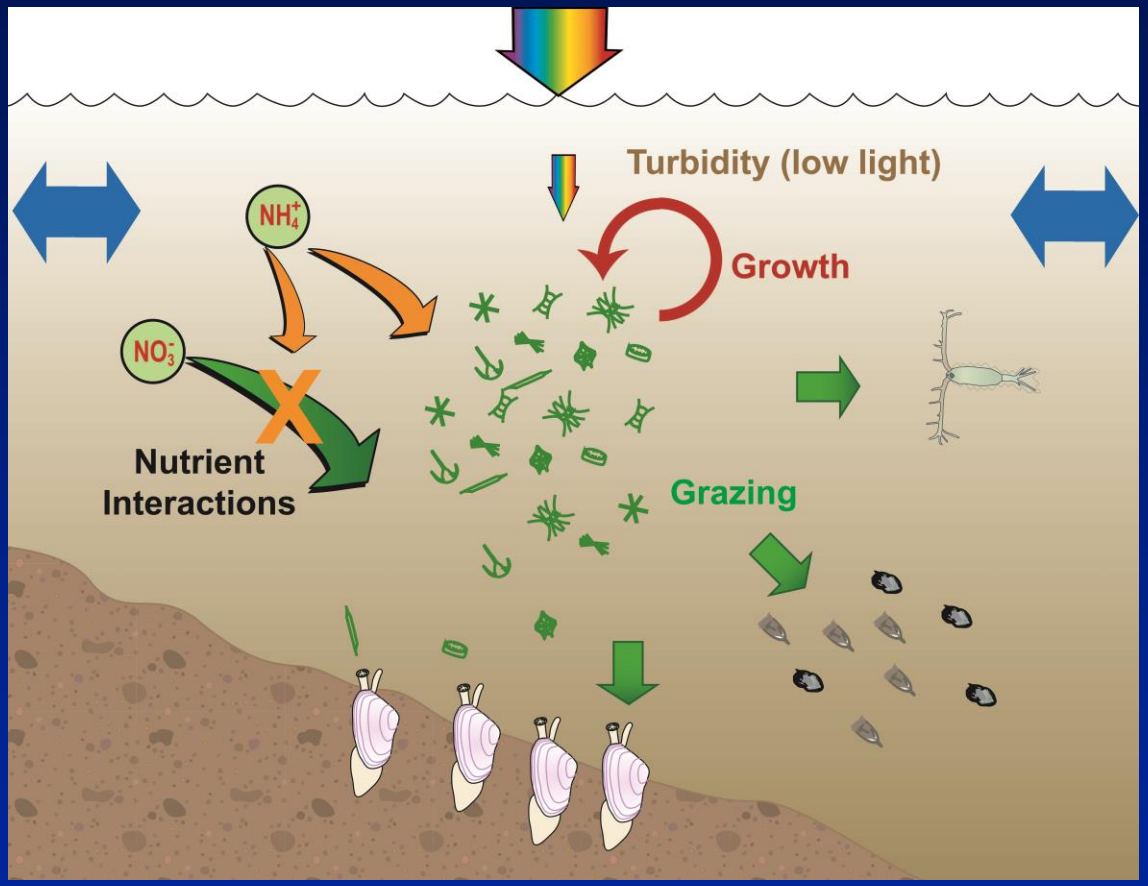


Kimmerer & Thompson
2014 Estuaries & Coasts

2. Limits to primary production: Ammonium inhibition

- Ammonium Inhibition

2. Limits to primary production: Conceptual Model



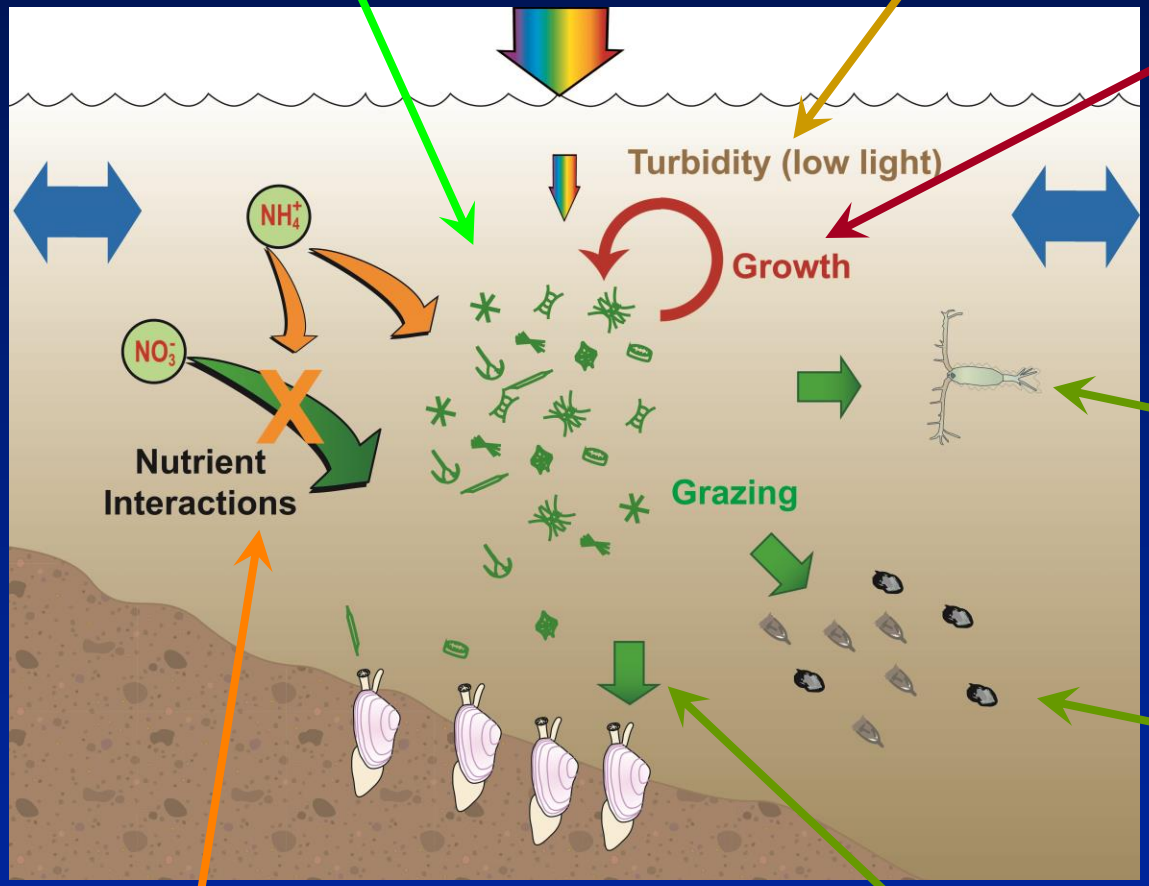
Symbols: Integration and Application Network,
UMD Center for Environmental Science

2. Limits to primary production: Conceptual Model

Chlorophyll, counts

Light profiles

^{14}C Measurements



Mixing diagrams

Growth rate & efficiency

Dilution experiments

Nutrient bioassays

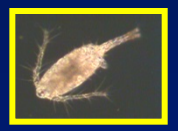
Clam biomass and filtration rate (spatially intensive surveys)

Symbols: Integration and Application Network, UMD Center for Environmental Science

3. Limits to zooplankton production: Low-salinity foodweb

Pelagic Fish

Acartiella



Limnoithona

Pseudodiaptomus

Clams

Microzoopl.

Bacteria

Transport

Flows to Clams

Transport

Diatoms

Other Phyto-plankton

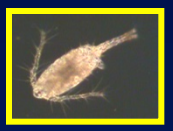
POC

DOC

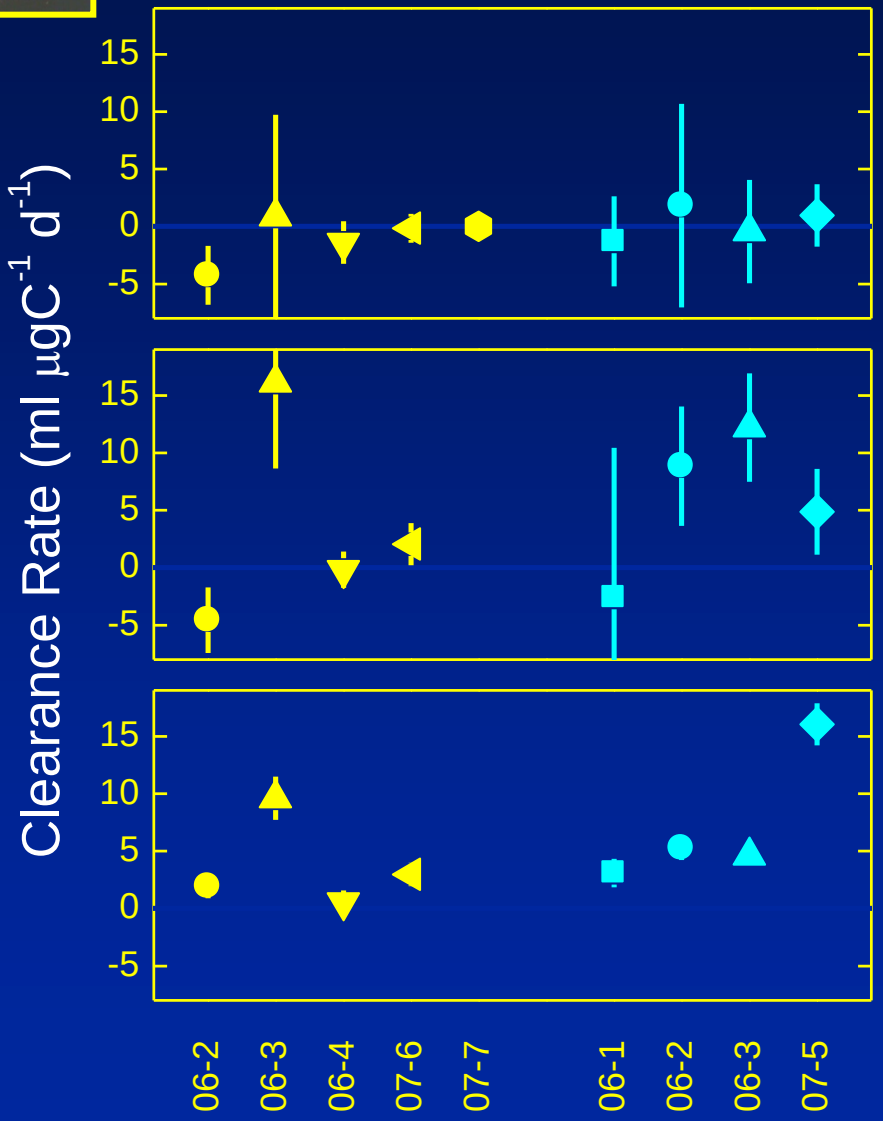
Ammonium

Nutrients

3. Limits to zooplankton production: Foodweb



Limnoithona *Pseudodiaptomus*



Chlorophyll

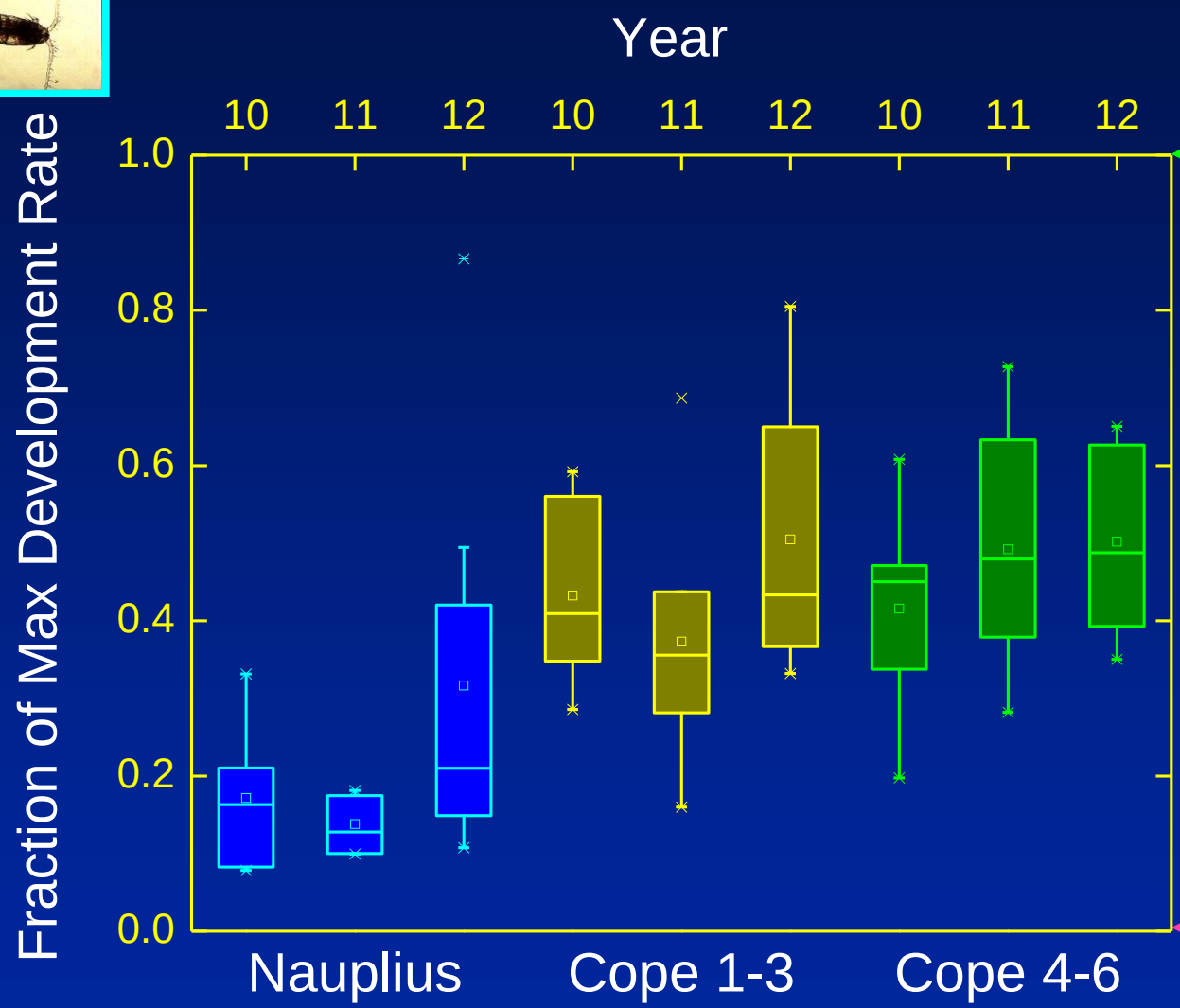
Naked Ciliates

Tintinnid Ciliates

Both species ate mostly ciliates

York et al.
2013 Estuaries & Coasts

3. Limits to zooplankton production: slow development



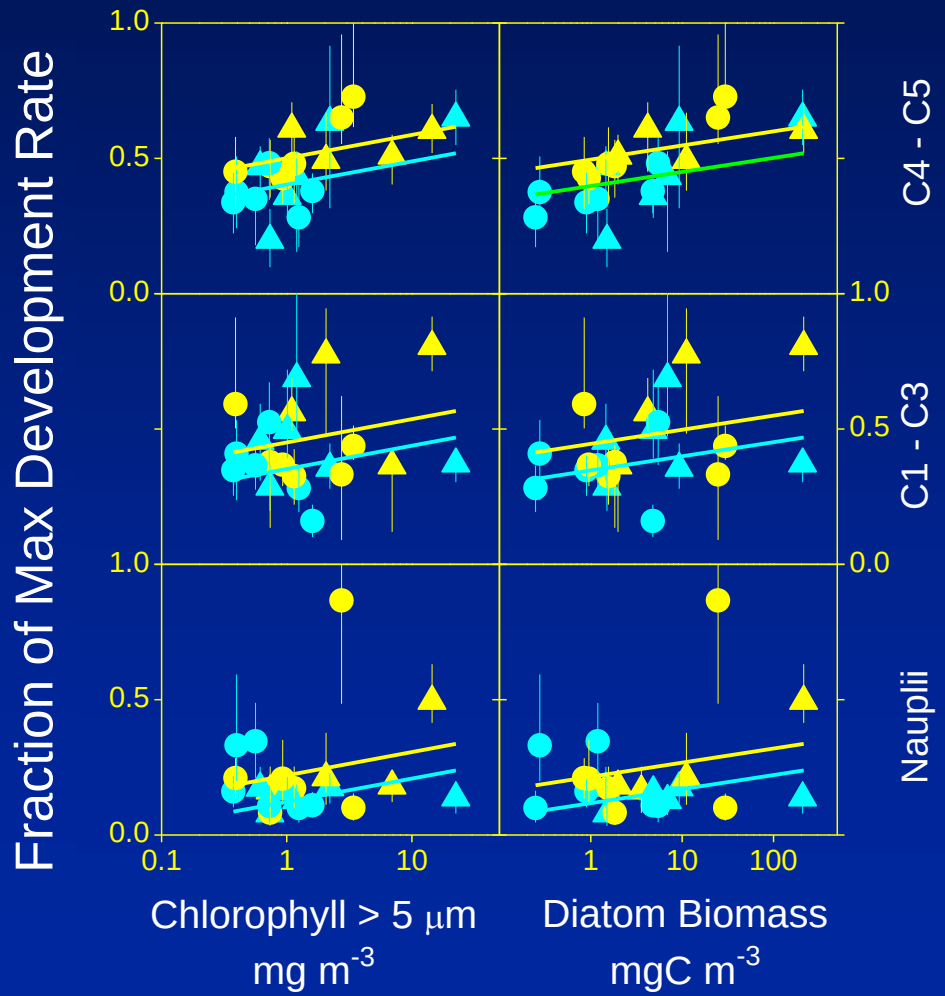
Max (lab) development rate

No development

Kimmerer et al.
Fall Habitat study

3. Limits to zooplankton production: slow development

Development Rate ∝ Phytoplankton Biomass



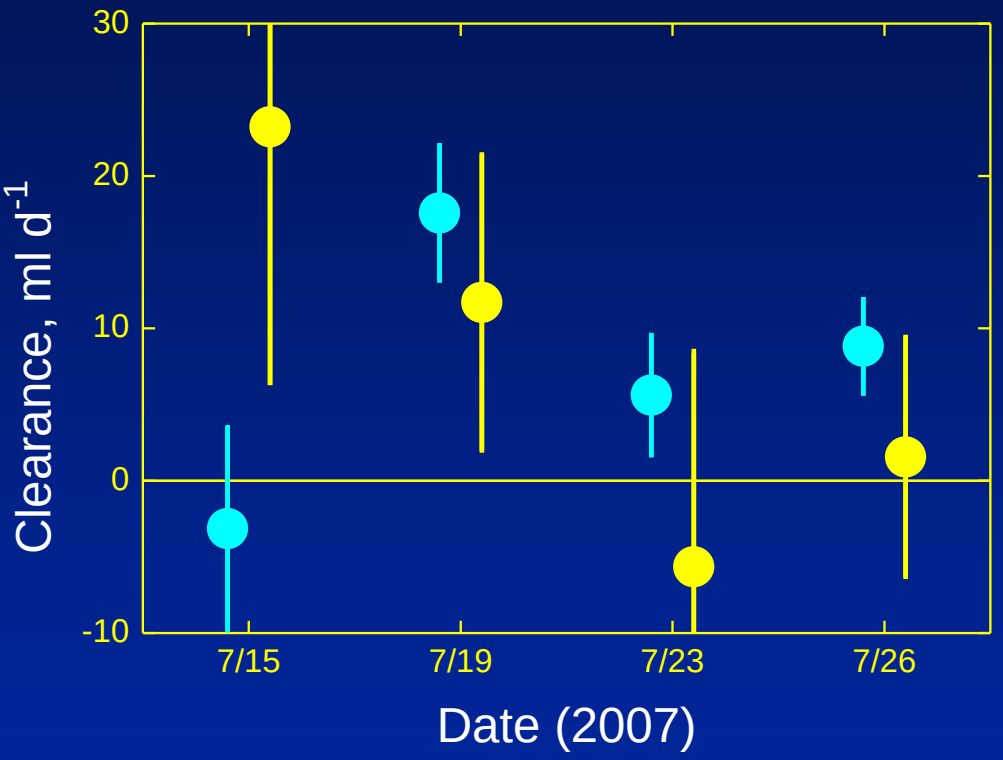
Sac SJR

Freshwater

Low Salinity

Kimmerer et al.
Fall Habitat study

3. Limits to zooplankton production: predation

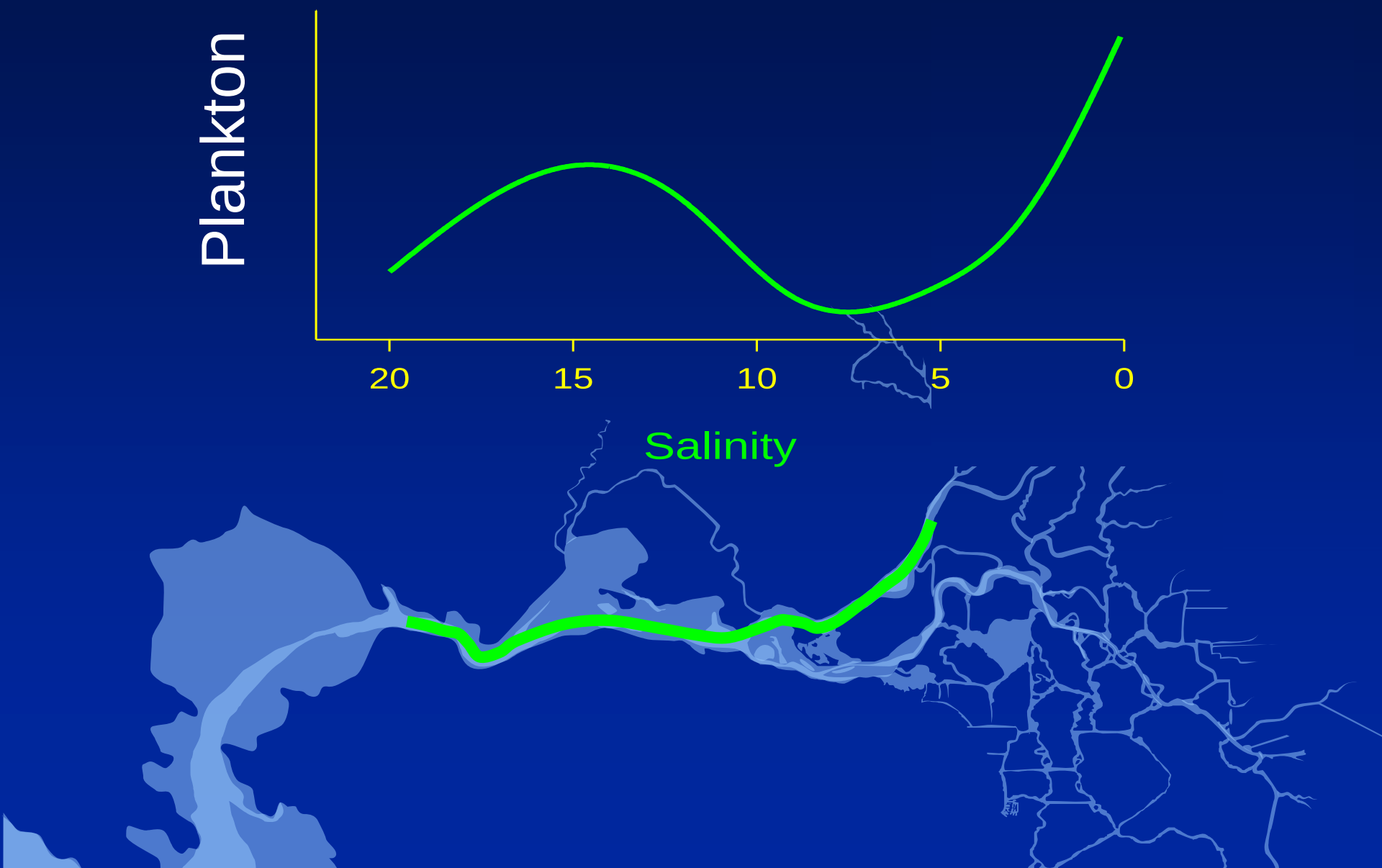


Acartiella

Limnoithona

York et al.
2013 Estuaries & Coasts
& Slaughter et al. in prep.

4. Spatial subsidies: Conceptual model



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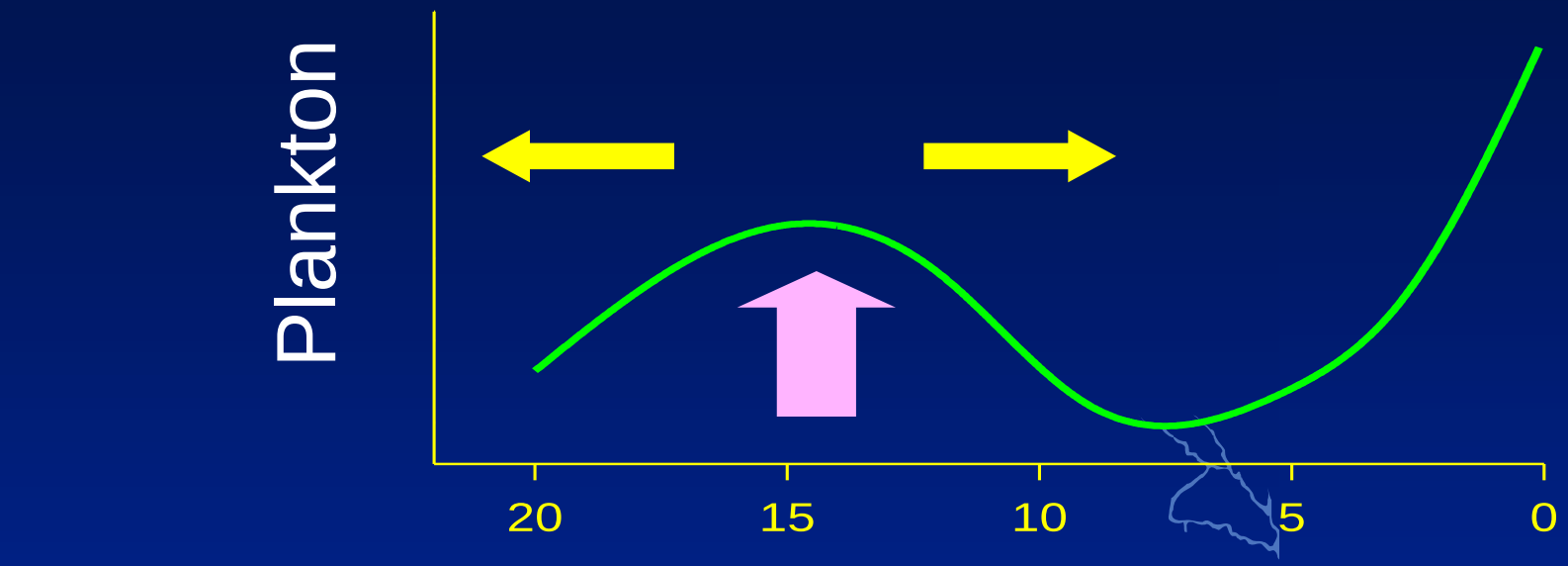

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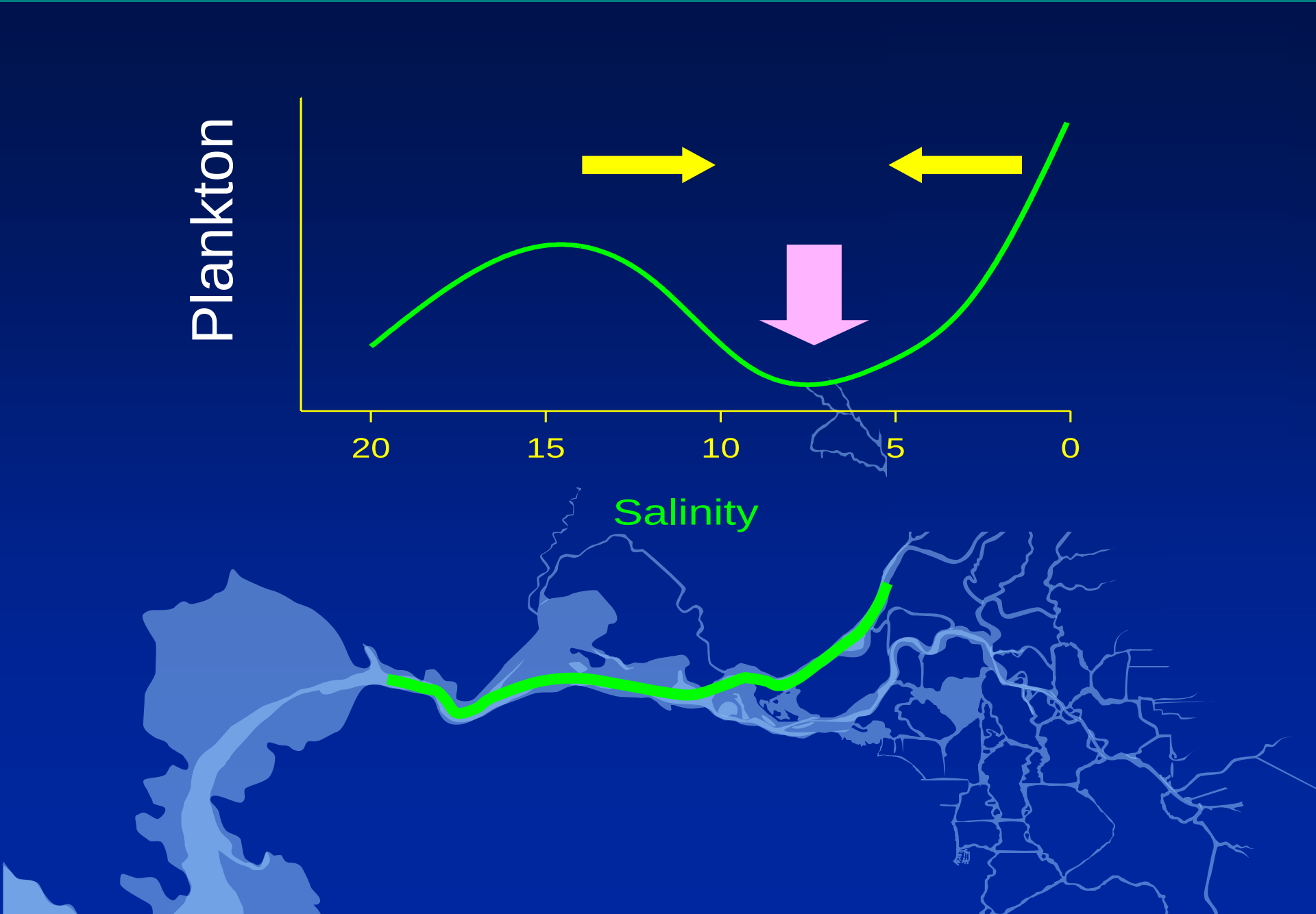
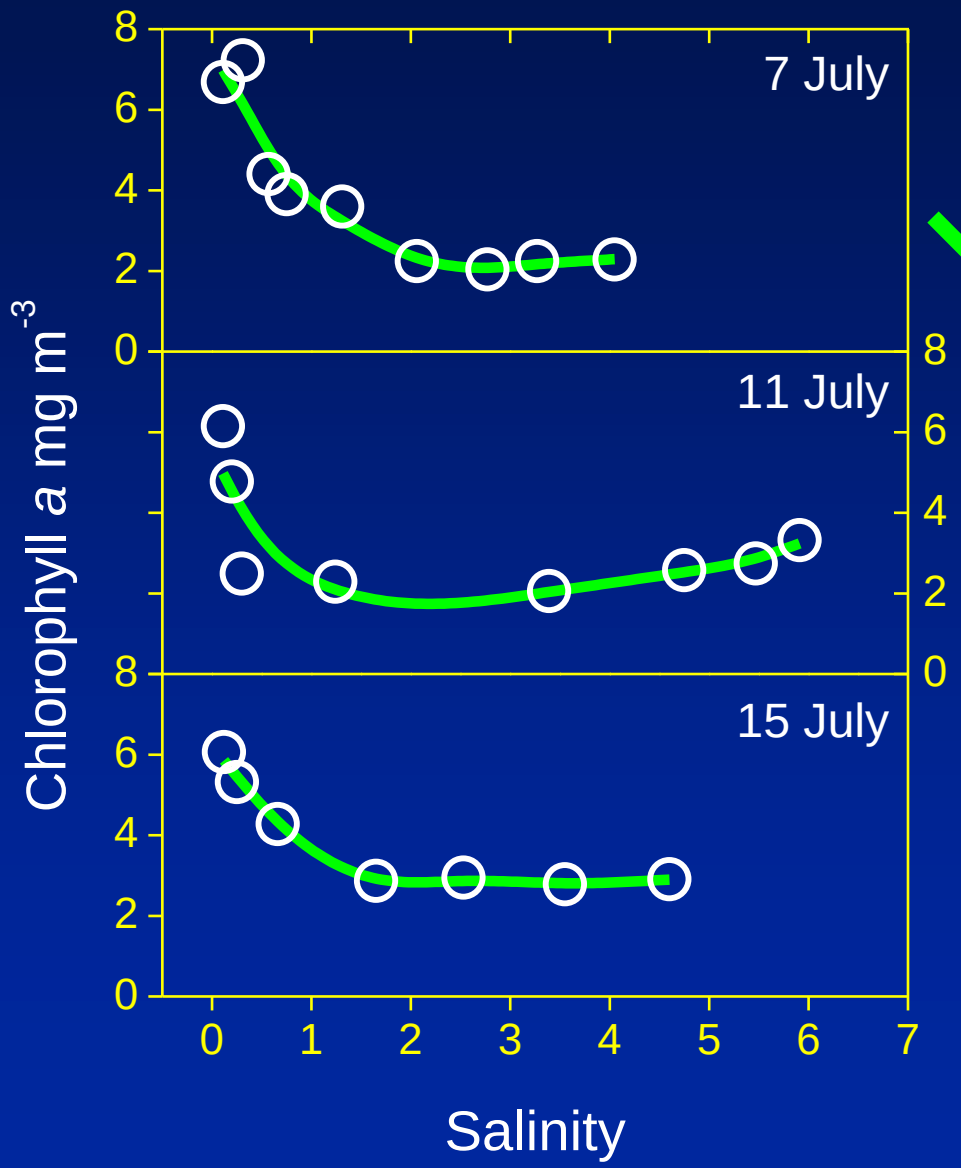
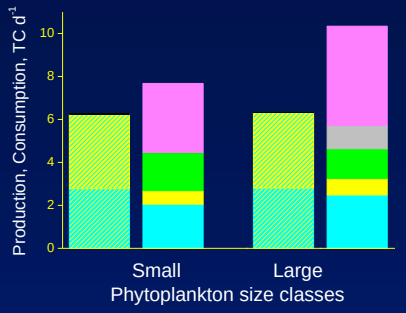
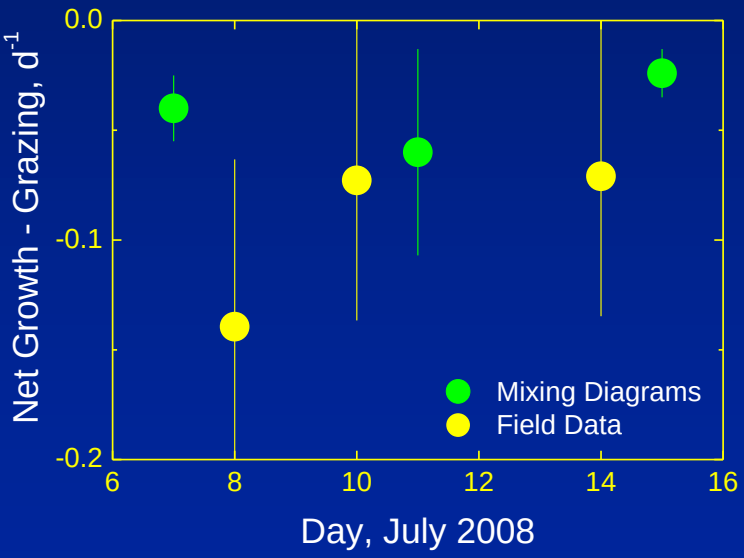


4. Spatial subsidies: phytoplankton

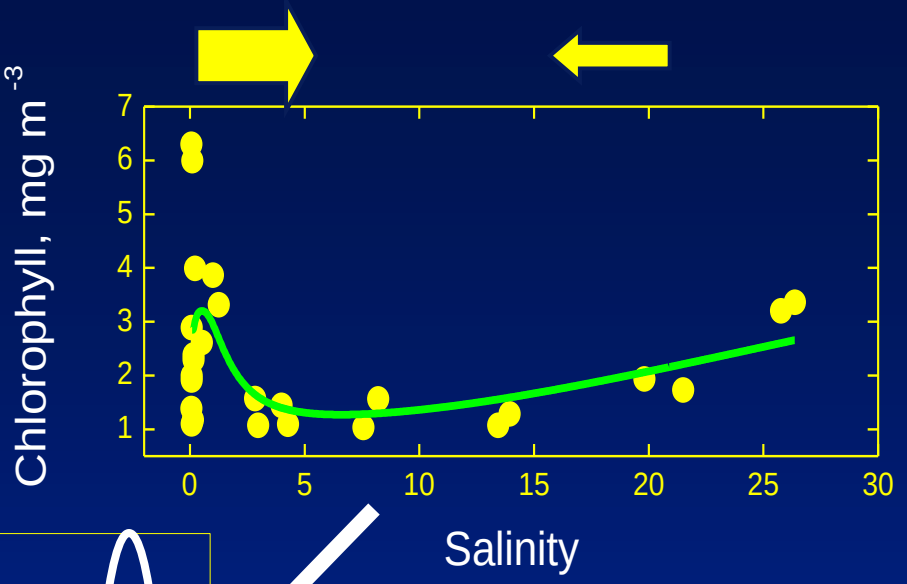


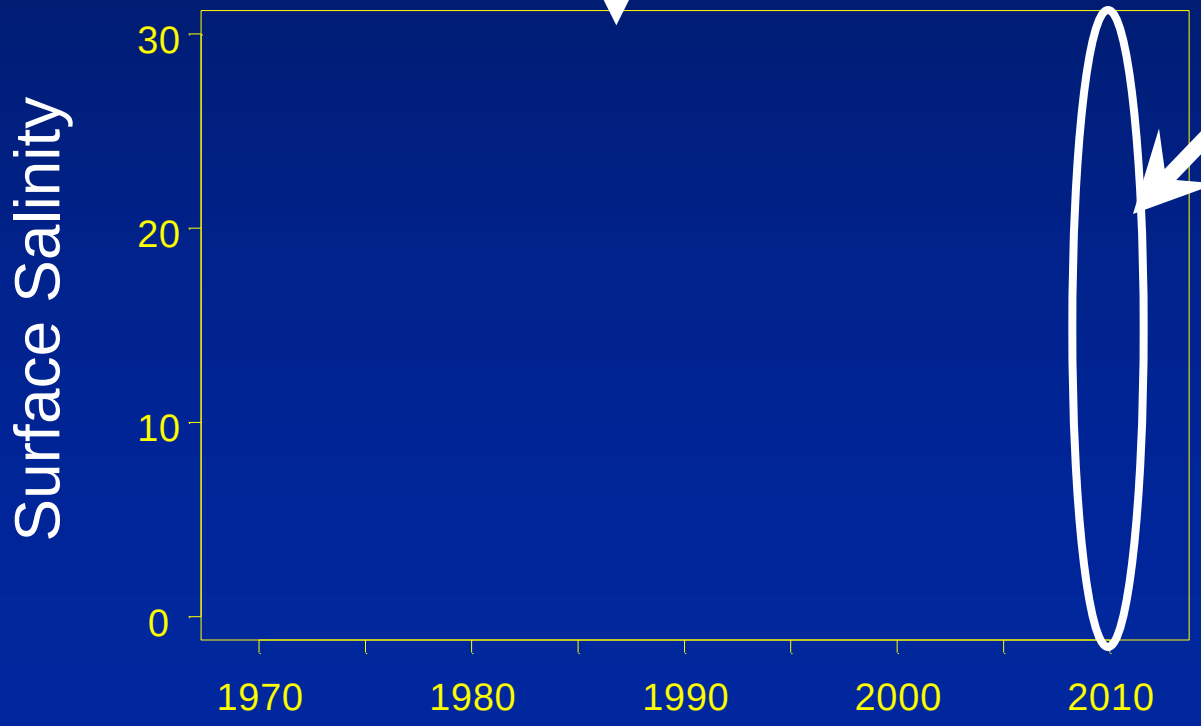




Kimmerer & Thompson
2014 Estuaries & Coasts

4. Spatial subsidies: phytoplankton





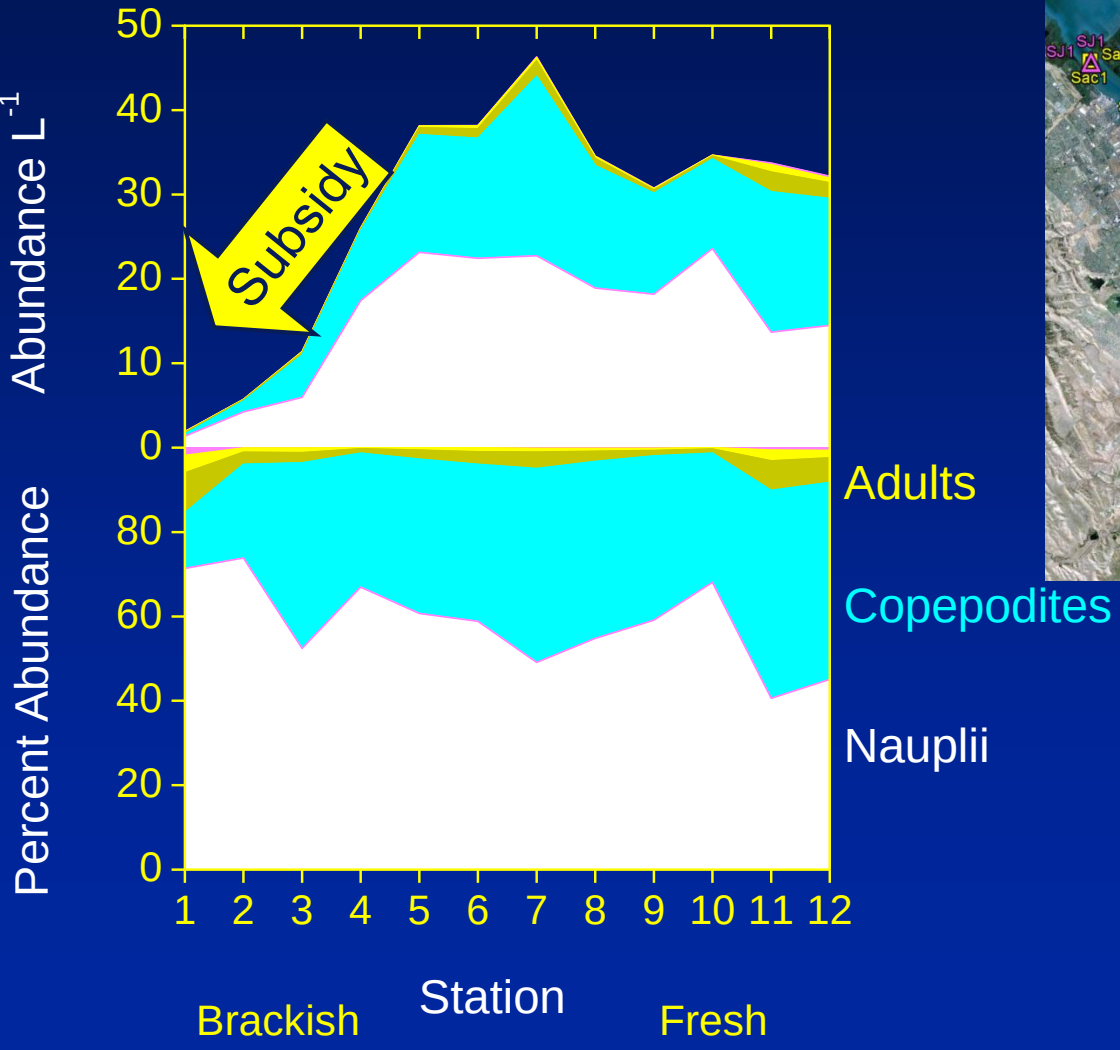
May – October
Chlorophyll, mg m^{-3}

1 2 5 10 20

Kimmerer & Thompson
2014 Estuaries & Coasts

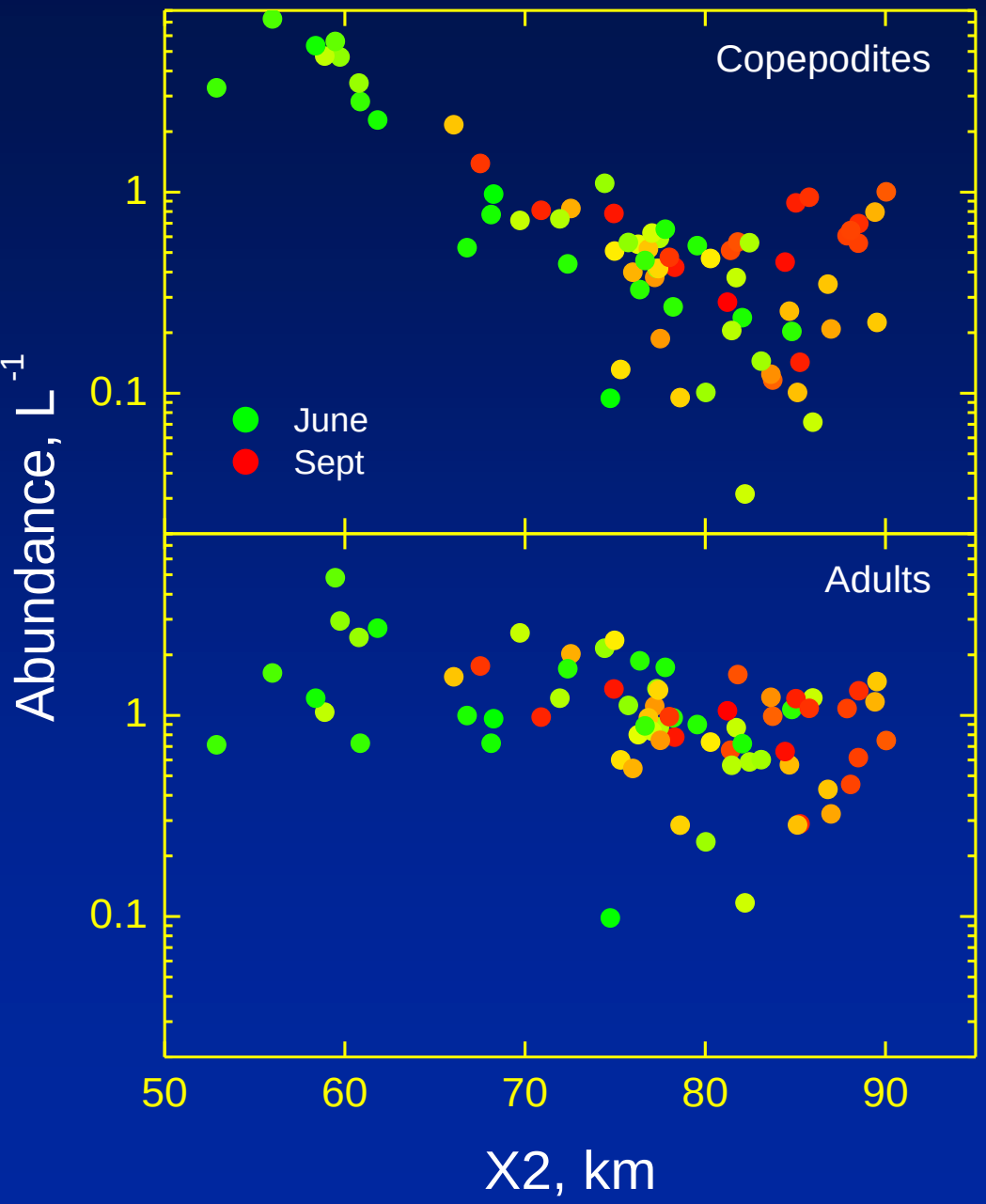
4. Spatial subsidies: copepod distributions

Pseudodiaptomus forbesi



Kimmerer et al.
Fall Habitat study

4. Spatial subsidies: copepods in the Low-Salinity Zone



Pseudodiaptomus forbesi

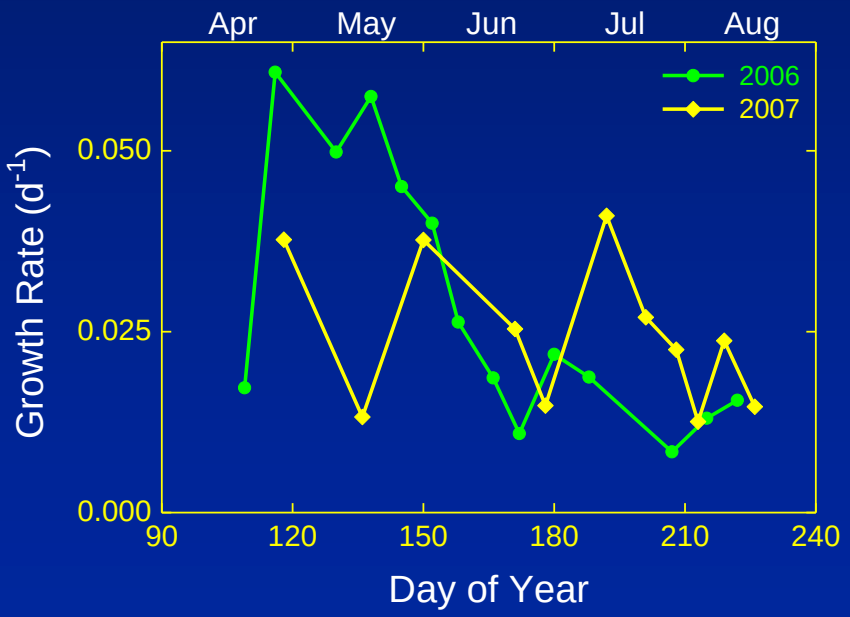
IEP monitoring data

5. How to design an estuarine copepod: Method 1

- Phytoplankton are small — Eat ciliates
- Low food supply — Low feeding rate
- Most fish are visual predators — Small, cryptic
- Few filter-feeding predators — Slow growth OK

0.5 mm

Limnoithona tetraspina

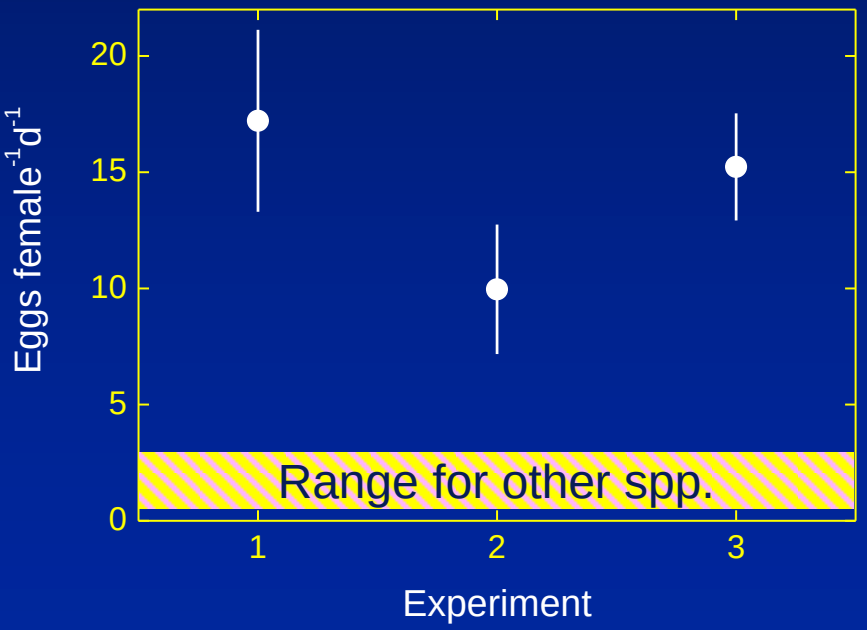


Gould and Kimmerer 2010 MEPS

5. How to design an estuarine copepod: Method 2

- Phytoplankton are small — Don’t eat ‘em
- Low food supply — Eat copepods
- Most fish are visual predators — Grow fast
- Few filter-feeding predators — Doesn’t matter

Acartiella sinensis

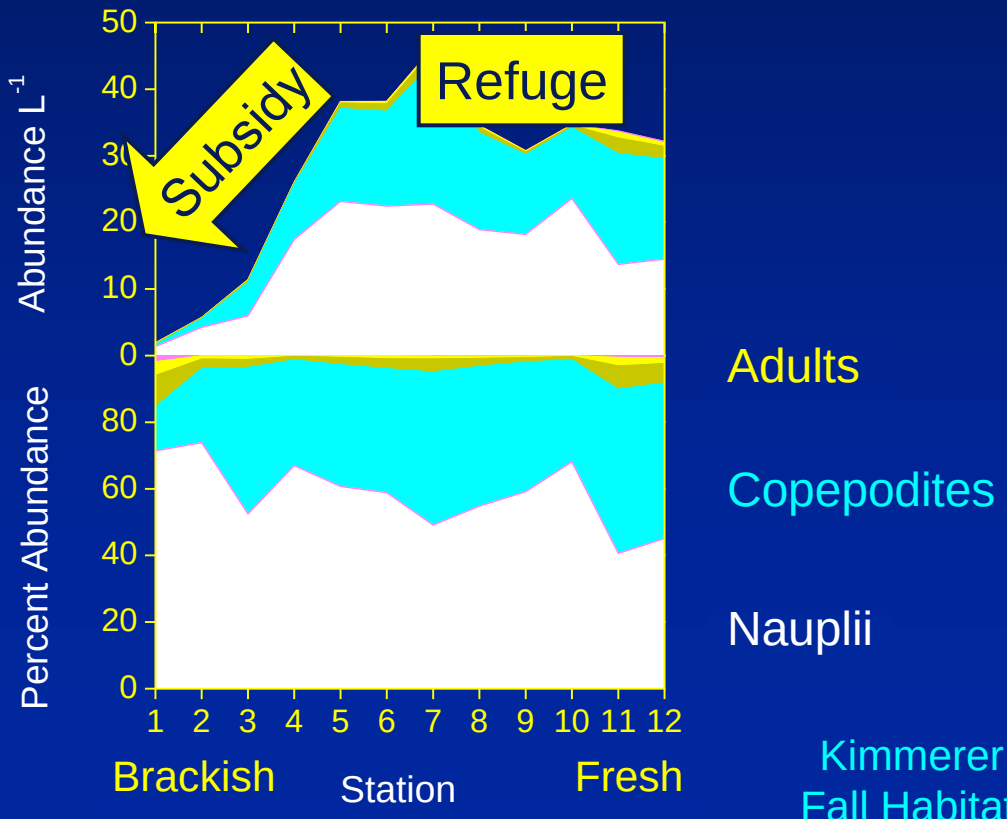


Slaughter et al.
Fall Habitat study

5. How to design an estuarine copepod: Method 3

- Phytoplankton are small — Be omnivorous
- Low food supply — ??
- Most fish are visual predators — Spatial refuge
- Few filter-feeding predators — Doesn't matter

Pseudodiaptomus forbesi

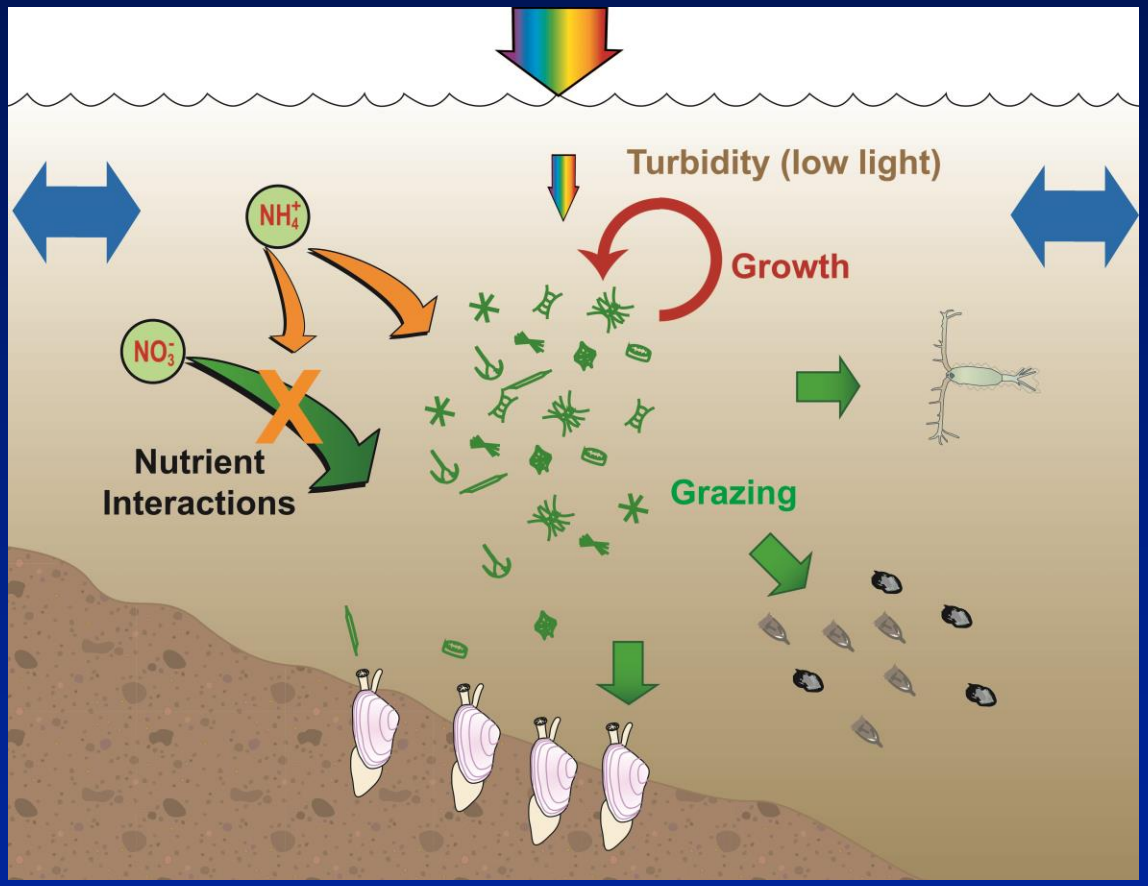


Kimmerer et al.
Fall Habitat study

6. Can we fix the low productivity?

- Alter productivity directly
- Increase the large-scale spatial subsidy
- Use small-scale spatial subsidies
  - Marsh restoration

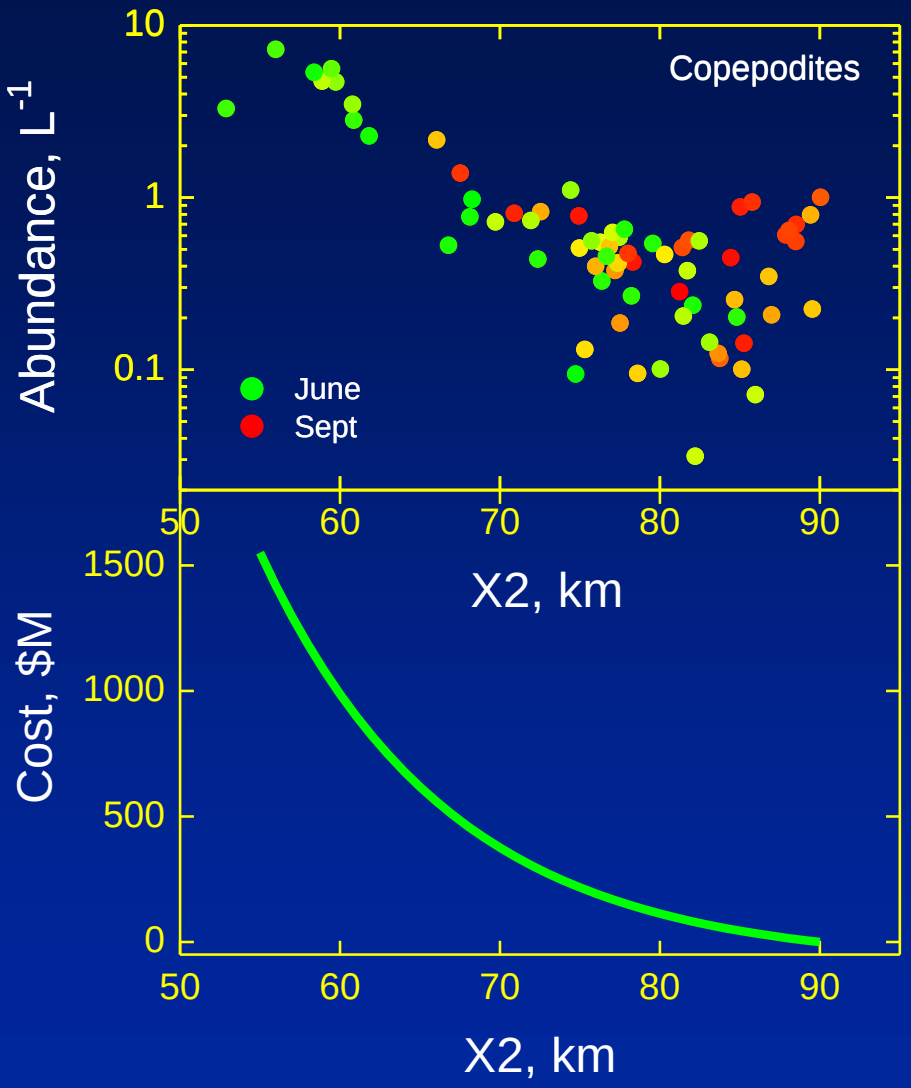
6. Can we fix the low productivity?



Ammonium?
Clams?
Turbidity?

Symbols: Integration and Application Network,
UMD Center for Environmental Science

6. Can we fix the low productivity? Large-scale export



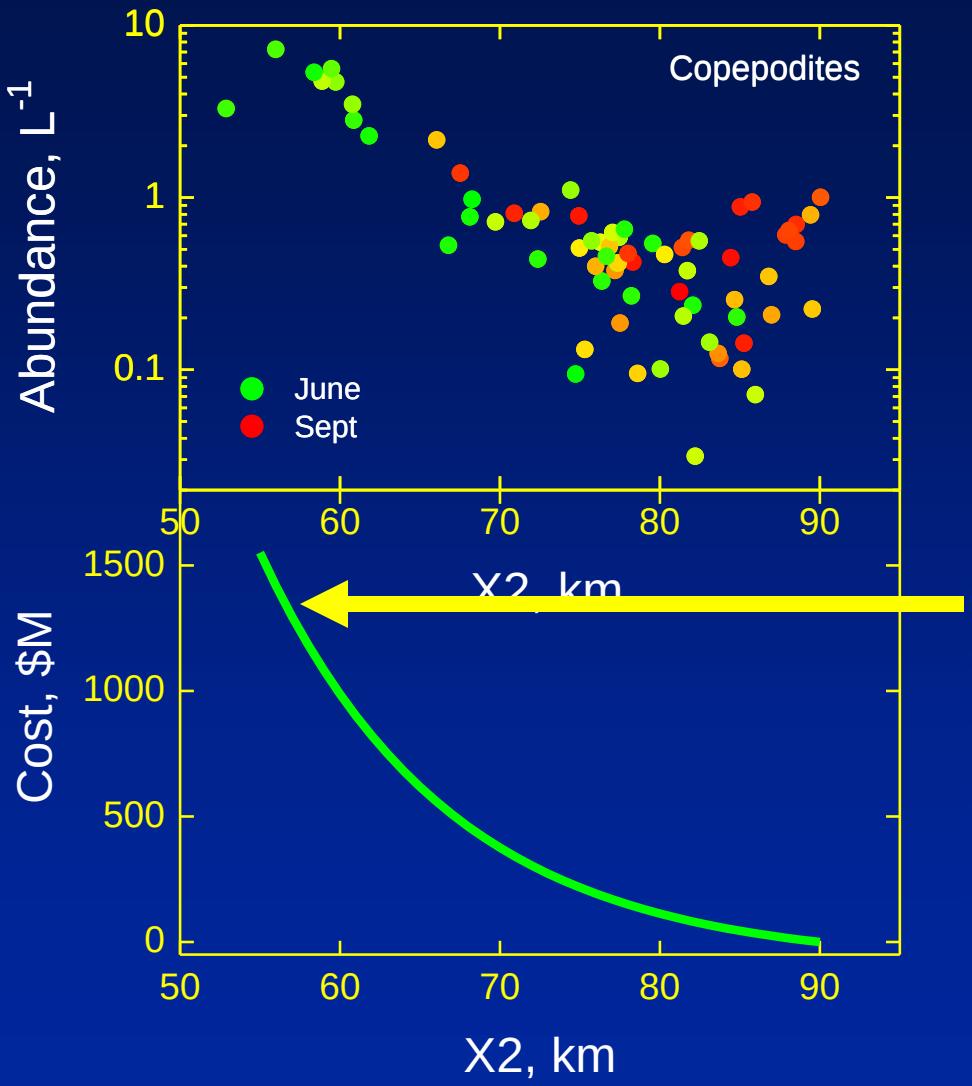
High flow increases subsidy to Low-Salinity zone

But it costs a bundle!

3 months @ $0.10 / m^3 or $120/AF

IEP monitoring data

6. Can we fix the low productivity? Large-scale export

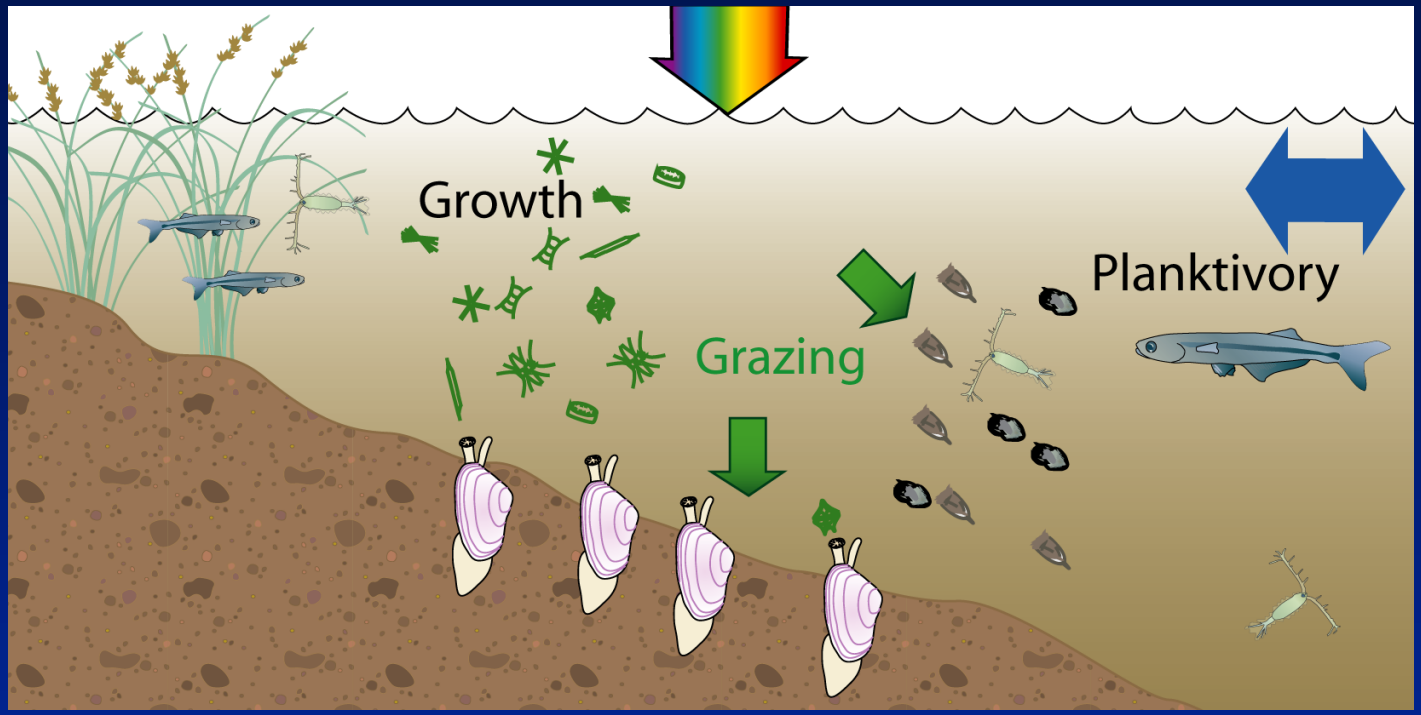


High flow increases subsidy to Low-Salinity zone

Total capacity of major Sacramento Valley reservoirs

IEP monitoring data

6. Can we fix the low productivity? Marsh export



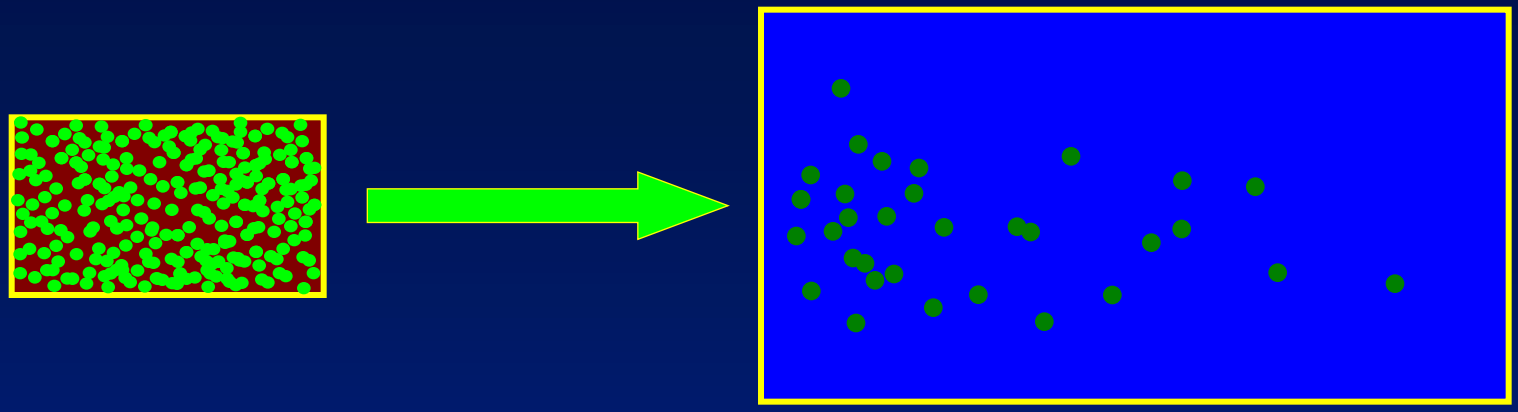
Shallow water:
High growth
Benthic grazing
Habitat for planktivores

Production:

Total organic matter	++
Phytoplankton	±
Zooplankton	-?

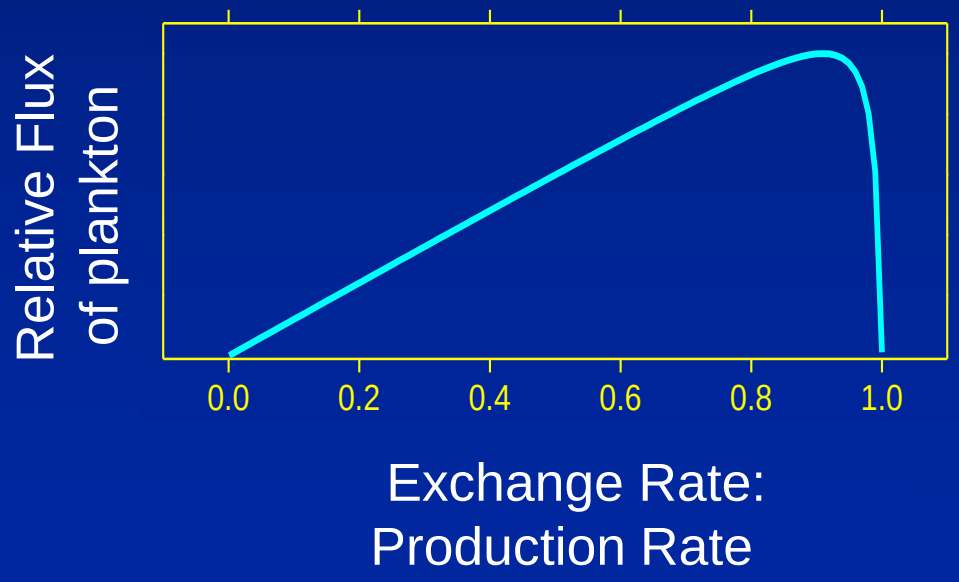
Symbols: Integration and Application Network,
UMD Center for Environmental Science

6. Can we fix the low productivity? Marsh export



Marsh

Open Water



How much stimulation by marsh production?

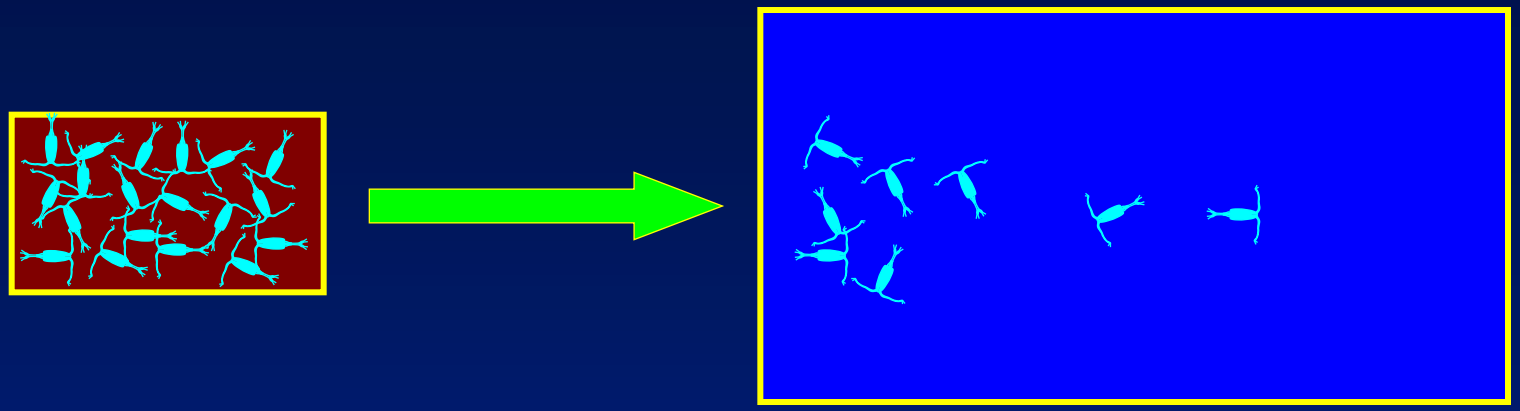
Phytoplankton

Zooplankton

Detritus

Nekton

6. Can we fix the low productivity? Export of plankton



Marsh		Open Water	
Area	1000 ha	Volume	0.5 km^3
Depth	2m	Copepods	3 $mgC\ m^{-3}$
Copepods	23 $mgC\ m^{-3}$		
Growth rate μ	0.1 d^{-1}		
Residence time	10d		

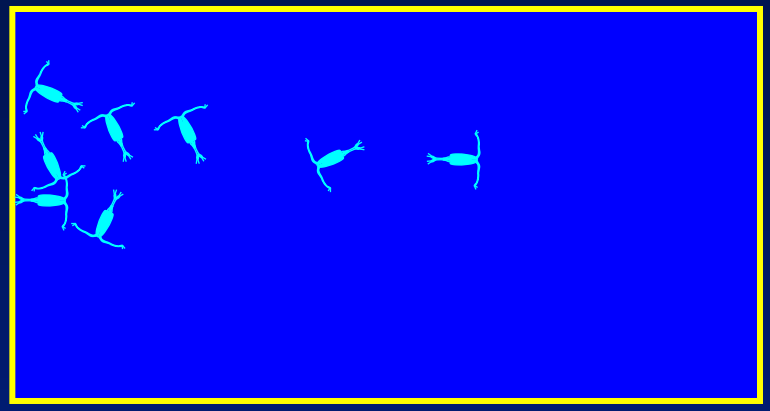
Resulting subsidy:
3% of existing copepod biomass d^{-1}

6. Can we fix the low productivity? Literature review

Flux of zooplankton to and from marshes

- Lake zooplankton abundance low in shoals
- Marsh in NY a sink for zooplankton
- Australian tidal creek a sink for copepods
- Saltmarsh a sink for copepods, source for larvae
- China Camp: marsh a sink for mysids
- Liberty Island: source or sink

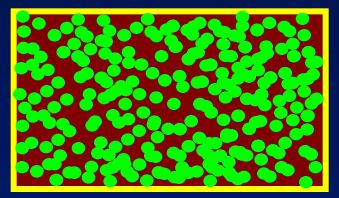
7. Some key questions: marsh subsidy

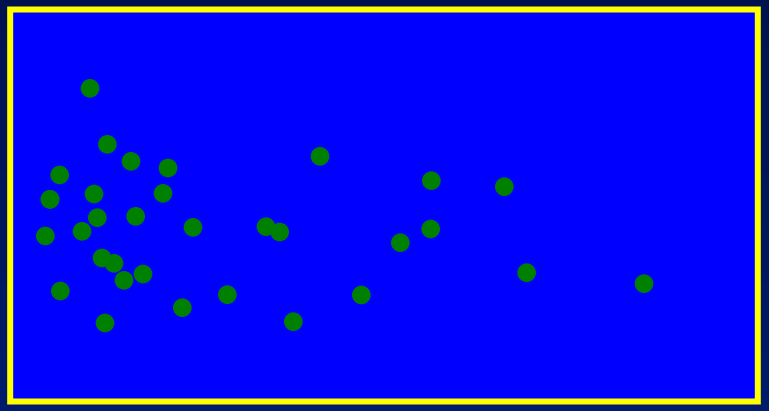


Can marshes subsidize open-water foodwebs, and under what conditions?

Field and modeling studies of fluxes between marshes and open water

7. Some key questions: marsh subsidy

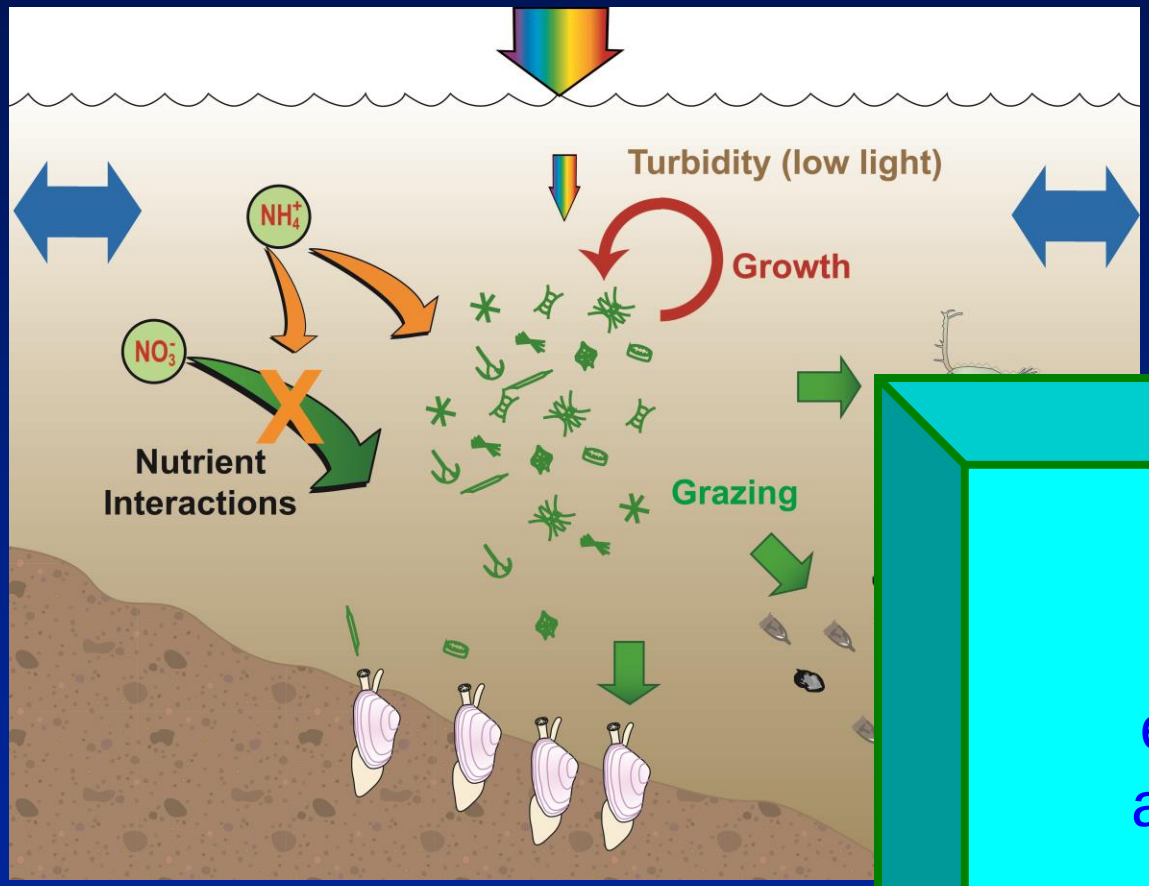




How much can marsh export of organic matter contribute to pelagic foodwebs?

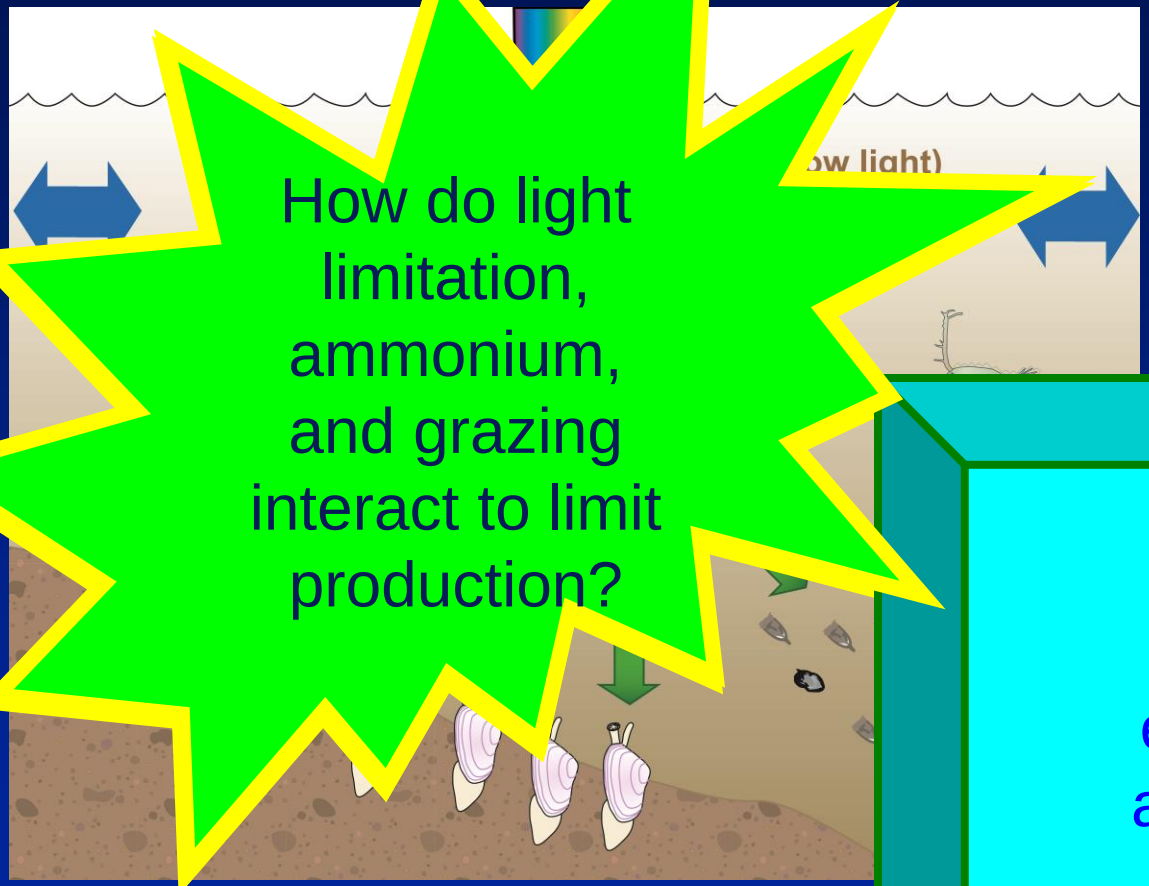
Field and laboratory studies of uptake of marsh detritus by pelagic organisms

7. Some key questions: phytoplankton production



Integrated experiments and modeling

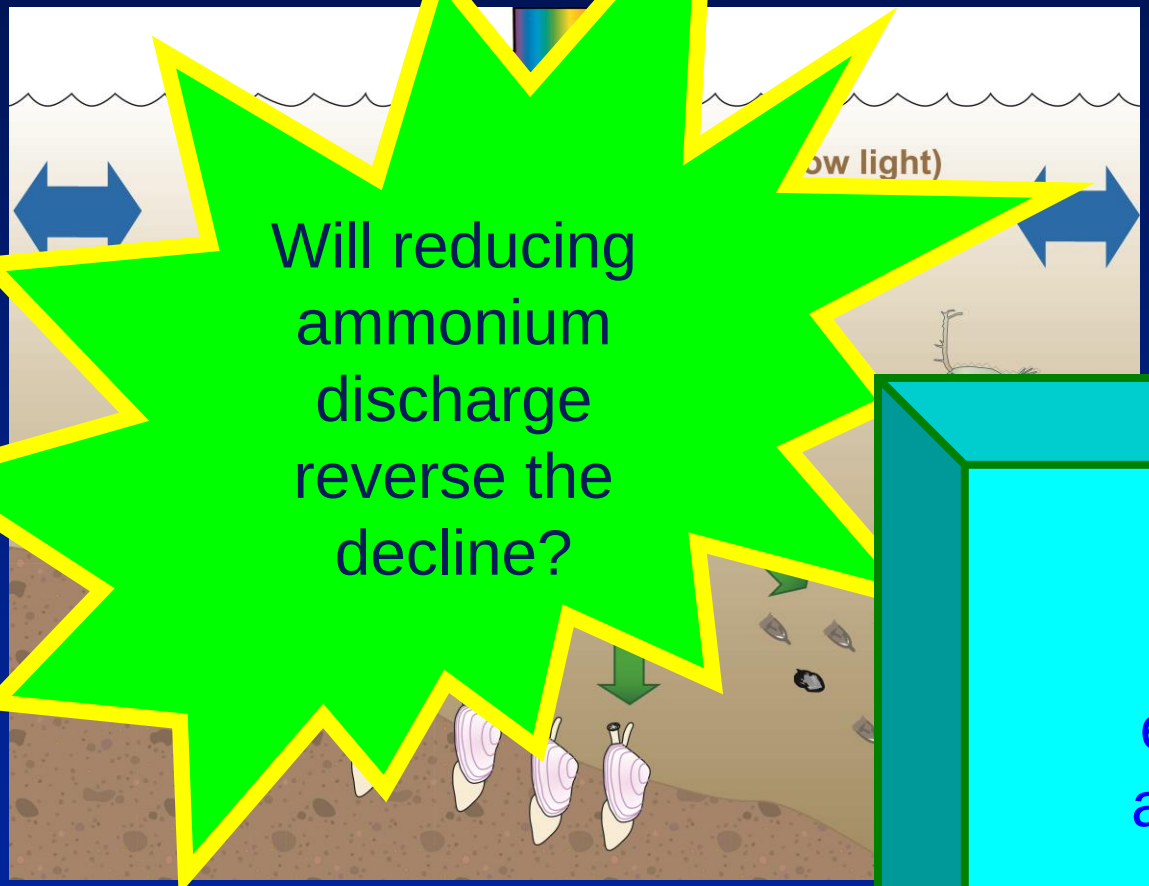
7. Some key questions: phytoplankton production



How do light limitation, ammonium, and grazing interact to limit production?

Integrated experiments and modeling

7. Some key questions: phytoplankton production



Will reducing ammonium discharge reverse the decline?

Integrated experiments and modeling

Summary

- Plankton move with the water
  - Use their frame of reference
- Three reasons for low foodweb productivity
  - Light limitation
  - Grazing
  - Ammonium concentration
- Three unlikely remedies
  - Increase outflow
  - Get rid of clams
  - Plankton farms
- Three potential remedies
  - Reduce ammonium loading
  - Marshes as plankton factories
  - Detrital output of marshes

Will this be science-based, or faith-based?

Summary

- Plankton move with the water
  - Use their frame of reference
- Three reasons for low foodweb productivity
  - Light limitation
  - Grazing
  - Ammonium concentration
- Three unlikely remedies
  - I
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Will this be science-based, or faith-based?

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…

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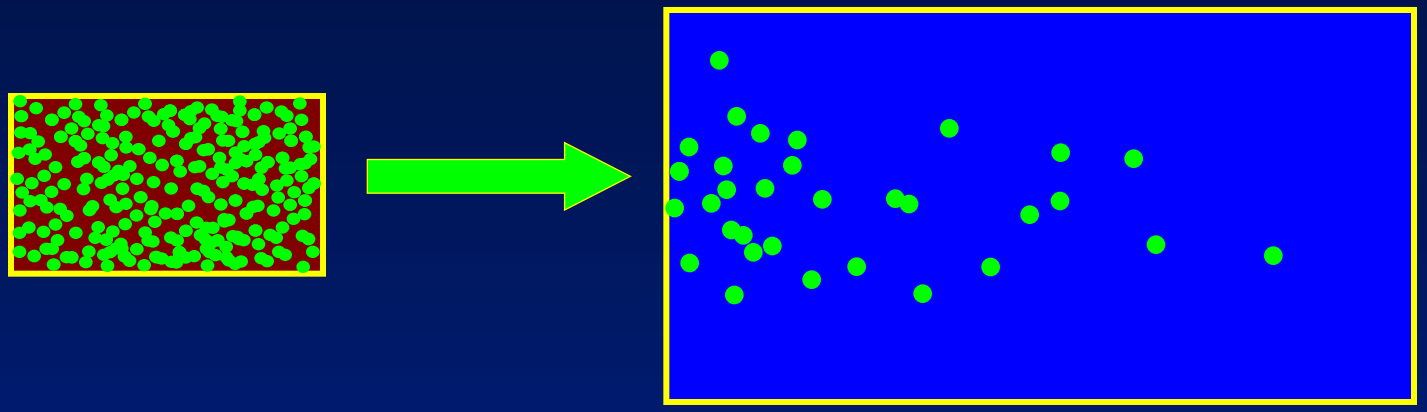
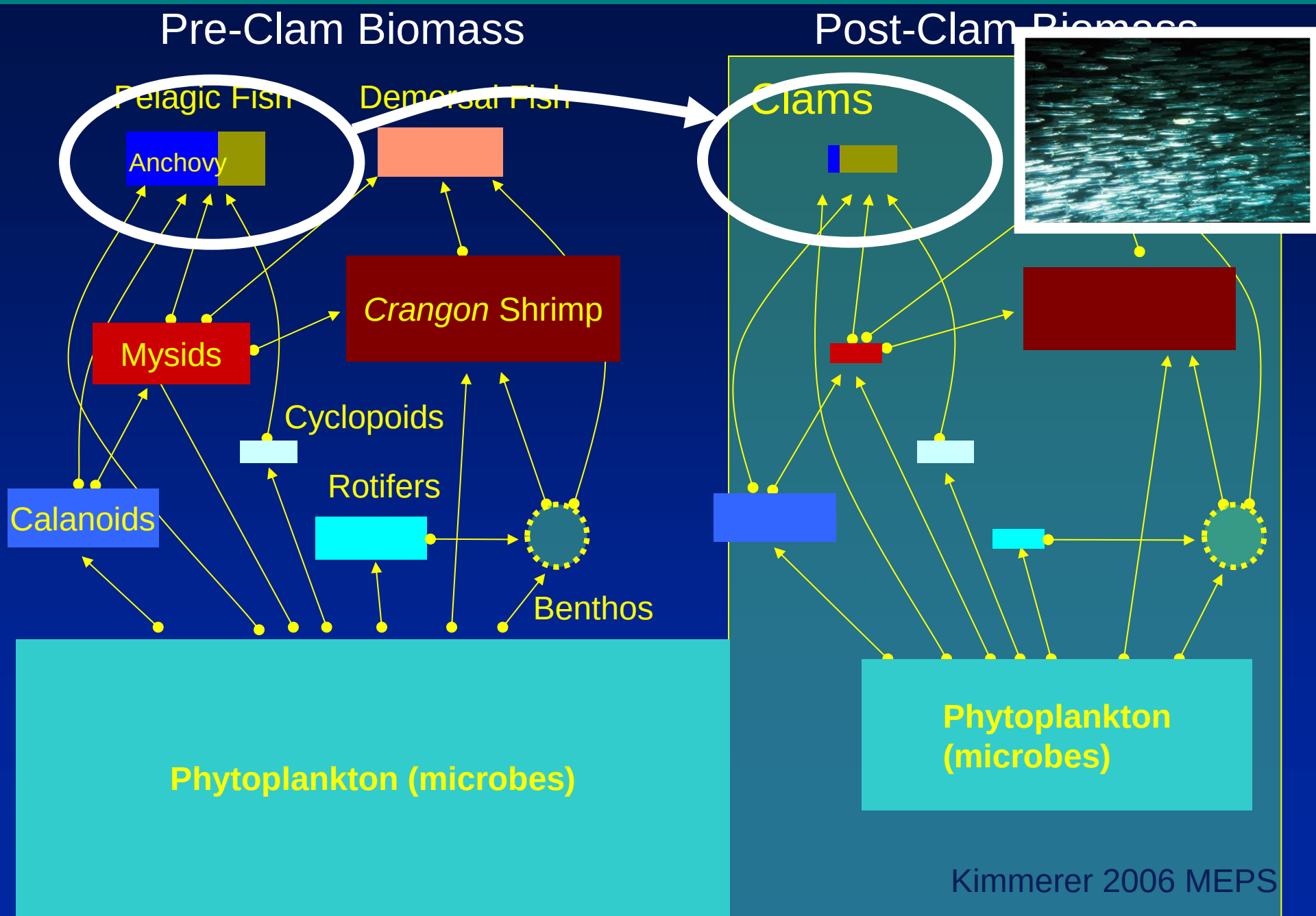
Subsidies from marsh: phyto model



Area	1000 ha	Volume	0.5 km^3
Depth	2m	Phytoplankton	73 mgC m^{-3}
Phytoplankton	900 mgC m^{-3}		
Growth rate μ	0.86 d^{-1}		
Microzoo grazing	60% μ		
Residence time	10d		

Resulting subsidy:
5% of existing phytoplankton biomass d^{-1}

Lesson 9: Foodweb interactions can be subtle



Zooplankton as "ecological filters" *

How does variation in phytoplankton productivity translate to variability in fish recruitment?

Characteristic	Efficiency of transfer to fish	
	Low	High
Phytoplankton size	Small	Large
Seasonal pattern (vs. fish)	Unpredictable	Predictable
Sensitivity to food	Low	High
Reproductive mode	Egg carriers	Broadcast spawners
Palatability / nutrition	Low	High
Zooplankton size (fish size)	Small	Large
Detectability (feeding mode)	Low	High
Catchability (feeding mode)	Low	High
Foodweb length	Long	Short